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# Health Hazard Scenarios in Italy after the COVID-19 Outbreak: A Methodological Proposal

**(doi: 10.14650/101721)**

Scienze Regionali (ISSN 1720-3929)
Fascicolo 3, settembre-dicembre 2021

# Health Hazard Scenarios in Italy after the COVID-19 Outbreak: A Methodological Proposal

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**Abstract:** The health emergency (COVID-19) in Italy had a great impact mainly in the Northern part. The geographical and environmental similarities observed between this area and the Wuhan area in the Province of Hubei (China), led to the basic hypothesis of this paper, namely how the presence of atmospheric pollutants can generate stress on the health conditions of the population and thus determine the pre-conditions for the development of diseases of the respiratory system. The aim of the paper is to produce three different hazard scenarios in Italy using the AHP method (Spatial Analytical Hierarchy Process) and thirteen information levels grouped into classes respectively related to environmental, climatic and land management factors.

**Keywords:** SARS-CoV-2, hazard map, multicriteria analysis.
**JEL classification:** R58, R52, O21.

## 1. Introduction

Coronavirus disease 2019 (COVID-19) was first officially identified in Wuhan city, Hubei Province, China in December 2019. COVID-19 has been confirmed as a pandemic by over 140 countries, with an estimated fatality rate of between 1.3% and 4.5% (Istituto Superiore della Sanità,

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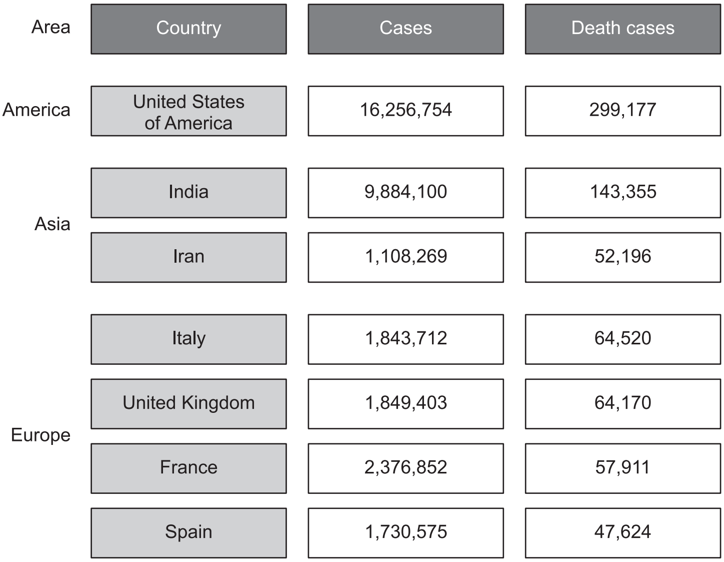
ISSN 1720-3929
Scienze Regionali, vol. 20, 3/2021, pp. 327-354

2020; World Health Organization, 2020) as estimated in the early stages of the pandemic and an $R_0$ – that measures the number of subjects that can be infected by a single individual during their entire period of infection starting at time 0 – estimated between 2.2 and 6.7 (Liu *et al.*, 2020). Italy was severely hit by COVID-19 from February 2020, after its outbreak in China at the beginning of January. Italy has been one of the principal countries in the early pandemic for deaths out of Hubei Province and mainland China, in the world, putting it on the front line of the epidemic concentration and diffusion. According to data published by the European Union Agency ECDC (European Centre for Disease Prevention and Control), 15,083,443 cases of COVID-19 were reported worldwide from 31th December 2019 to 14th December 2020, including 375,147 deaths (Figure 1).

In particular in Europe, Italy (64,520), United Kingdom (64,170) and France (57,911) were the countries with the highest number of deaths as of 14 December 2020, while the United States of America (299,177) more recently emerged as the country among the ones with the highest number of cases and deaths (Desjardins *et al.*, 2020). The virus has begun to circulate strongly in many countries that had «won» the first battle with severe lockdowns (Xu, Li, 2020; Yu *et al.*, 2018). The disease, regardless of the numbers, has further highlighted the progressive destruction of natural resources, such as the reduction of the forest heritage and with it of the natural habitat and the progressive reduction of biodiversity, from pollution of environmental matrices: air, water and soil. In trying to put the process – still ongoing at the time of writing – within a geographical-epidemiological framework, we can recall some of the possible dynamics that accompanied the diffusion process. While waiting to observe the full behaviour dynamics after the end of the process, it is however appropriate to recall some brief considerations about the conditions that favoured the onset of the epidemic (geographical-epidemiological) and its trend. In particular, in examining the Italian COVID-19 outbreak, we observed some possible similarities from the geographical (metropolitan city, river and isotropic area), environmental (poor air quality, climate and land take) and socio-economic (commuting, concentration of urban functions residences, offices, rural factories, technological industries) points of view, that led to searching for elements of comparison in areas of major impact of the disease, such as Northern Italy, in the Po Valley and in the metropolitan region of Milan, and the original area of development, namely Wuhan in Hubei Province, in China (Murgante *et al.*, 2020b; Dettori *et al.*, 2020). Furthermore, the epidemic, as such, follows the wave trend: Onset, Youth, Maturity, Decay and Extinction (Figure 2).

In this work we focus on the hazard assessment, a component of the risk scenario analysis that occurs in the presence of extreme events such as those linked to the recent global pandemic. Before the COVID-19 epidemic, the health risk has always been a consequence of other risks, so much so that



| Area | Country | Cases | Death cases |
|---|---|---|---|
| America | United States of America | 16,256,754 | 299,177 |
| Asia | India | 9,884,100 | 143,355 |
| | Iran | 1,108,269 | 52,196 |
| Europe | Italy | 1,843,712 | 64,520 |
| | United Kingdom | 1,849,403 | 64,170 |
| | France | 2,376,852 | 57,911 |
| | Spain | 1,730,575 | 47,624 |

**Figure 1:** Country, Cases and death from the European Center for Disease Prevention and Control.
**Source:** https://www.ecdc.europa.eu/en.

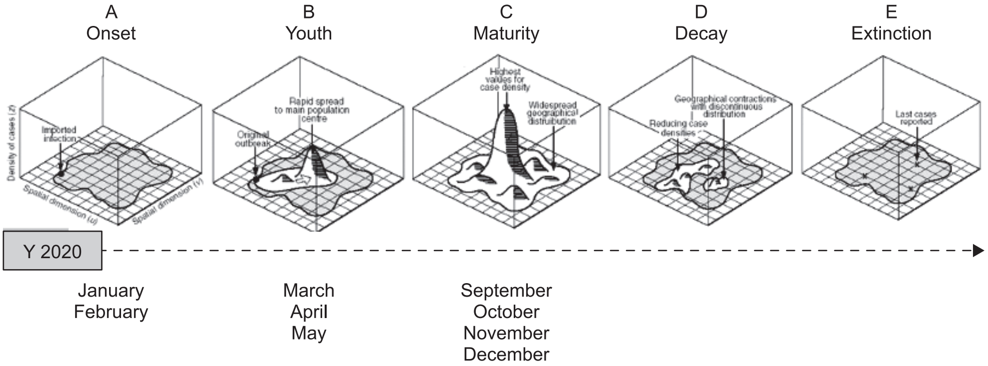


**Figure 2:** Wave trend.
**Source:** Author's elaboration from Cliff, Haggett (2006), adapted to the Italian case.

it is defined as second degree, closely related and consequent to a different type of disaster (Borruso *et al.*, 2020).

In this framework, a risk scenario can be defined, in general, as the space in which different players move and the territorial system components interact, including socio-economic and demographic dynamics (Las Casas, Scardaccione, 2006). In the preparation of the risk scenarios the requested context parameters concern three main aspects: systemic vulnerability, hazard and exposure.

Of the above-mentioned aspects, systemic vulnerability is the most crucial one to identify. It is defined, as well, by a physical and a functional vulnerability. In the specific case of a global pandemic, physical vulnerability can be defined as a measure of the physical damage suffered by an individual as a result of an extreme event. A critical component of the physical vulnerability in the case of COVID-19 pandemic – as in the studies still in progress on the determinants of the disease, that highlights among the major worsening factors the presence of past diseases, and the most accidental environmental factors – can be identified in the share of population over 65 years, the segment of the population that was the most vulnerable to COVID-19 in terms of the number of deaths and people infected (Youmni, Mbarek, 2020), especially in the first wave, also recently confirmed in the second wave (Bontempi, 2020). Functional vulnerability, on the other hand, concerns not the physical characteristics of the individuals but rather the consequences that could derive from their behaviour. We identify this vulnerability, for example, in commuting flows and in an individual's own ability to carry out his normal activities. With reference to the global pandemic, we identify the functional vulnerability as the loss of the capacities of an individual who is a doctor or any worker to carry out his normal activities because he is infected by the virus. The systemic vulnerability is therefore the interaction of these two components; it is a sort of total functionality of the system composed by all the individuals and functionalities who are part of it.

Hazard can be defined as the threat of stress or perturbation to a system and what it represents (Kasperson, Kasperson, 2001). It is an expression of the interaction of various factors (environmental, climatic and land) and represents, together with physical vulnerability and exposure, the functionality or dysfunctionality of a territorial system. The exposure is identifiable in the total population at risk in a given area (Varnes, 1984). A system's functionality and dysfunctionality will be discussed in terms of the number of those infected and their recovery time in the discussion paragraph.

Among the number of factors influencing the COVID-19 diffusion in Italy, the basic hypothesis of this research is that the presence of atmospheric pollutants can generate stress for the health conditions of the population and determine the pre-conditions for the development of both diseases related to the respiratory system and complications related to them, including those that are dangerous for life, which can explain the excess of lethality that occurred in the Po Valley (Zoran *et al.*, 2020). Furthermore, the particular climatic conditions of the Po Valley, including thermal inversion, typical of the winter period, may have worsened the already compromised environmental situation deriving from air pollution (Ferrero *et al.*, 2019). In fact, $PM_{10}$ limit values were systematically and continuously exceeded between 2008 and 2017. This was confirmed in the European court ruling that condemned Italy for violating EU law on air quality, because it did not activate strategies to resolve or stem the serious health phenomenon (Judgment of the Court, 10

November 2020, http://curia.europa.eu/juris/documents.jsf?num=C-644/18). With these premises we analyzed the data relating to COVID-19 contagions and deaths at the provincial level, referred to a period after the strict lockdown measures introduced in Italy, useful for observing the phenomenon in a moment of very limited personal movement and limited economic activities, therefore without perturbations provided by human action. We hypothesized the existence of a relationship between air-related pollutants and the spread and lethality of the virus in the outbreak of the epidemic (Dettori *et al.*, 2020). We in particular considered a big geographical dataset from which we selected a set of indicators related to environmental, climatic and land conditions, finalized at realizing health hazard scenarios, through an interdisciplinary ecological approach to evaluate the phenomena in their complexity (Murgante *et al.*, 2020b).

In this sense we analyzed the spread of COVID-19 in Italy, on the basis of a theoretical and quantitative analysis on a large set of data built and analyzed by means of spatial analytical techniques in previous works and further improved and analyzed in the present research.

We have therefore used the ecosystem services approach in order to propose a comprehensive methodology that integrates the concepts of human well-being and health with indicators significant of ecosystem integrity and functionality (Chiabai *et al.*, 2018; Sandifer, Sutton-Grier, 2014). In order to model this complex relationship (Sandifer *et al.*, 2015), Habitat Quality and Degradation and Carbon Stock were assessed and mapped, as they are directly linked to land use and to the territorial transformations that occurred. These variables are therefore assumed to be representative of the potential of ecosystems to keep providing services and functions useful for human well-being (Mononen *et al.*, 2016), despite sensitivity to increasing anthropic pressures such as soil sealing or other land consumption phenomena, and spreading natural habitats' fragmentation. Our overall objective, therefore, is to provide a contribution to the recent scientific debate on revised health concepts (Charron, 2012; Lang, Rayner, 2012; Wallace *et al.*, 2015) that recognises the link between both biotic and abiotic components of ecosystems and human well-being but is still searching for an effective methodology to introduce these complex relationships into policies and recommendations that can be integrated into territorial multi-level governance processes (Ford *et al.*, 2015).

The first result obtained is the setting up of a database that includes environmental, climatic and land management factors that contribute to determining a hazard scenario for the possible spread of a virus such as COVID-19. In order to reduce the complexity of the decision-making process or specific policy design, a multicriteria analysis was performed by means of the Spatial Analytical Hierarchy Process (AHP) that allowed us to formulate three different hazard scenarios.

It is believed that through adequate climate mitigation policies based on sustainable land management objectives, as well as through the three hazard scenarios obtained, it is possible to support policies capable of improving the functionality of the urban system in terms of reducing risks for human health.

The rest of the paper is organized as follows. In Section 2 materials, data and methods are presented. Section 3 contains the results from the multicriteria decision analysis. A discussion is carried on in Section 4, while conclusions in Section 5, containing future developments, conclude the research.

## 2. Materials, data and methods

### 2.1. Materials

#### 2.1.1. Ecosystem service performance assessment

As part of the multidisciplinary ecological approach adopted for this work, selected results of a previous evaluation of the performance of ecosystem services, the geographic and climatic data set was integrated and the danger linked to the spread of a pathogen by different types of predisposing factors by utilizing the spatial MCA. Our hypothesis is that territorial transformations and land use changes over the last thirty years have led to a loss of ecosystem services and, consequently, a decline in the capacity for functions related to human well-being and health.

The relationship between the functionality of the environment and human health is being increasingly addressed (Fuller, Gaston, 2009), including in the discipline of urban and regional planning (Alamgir *et al.*, 2014; Alcaraz-Segura *et al.*, 2013; De Araujo Barbosa *et al.*, 2015; Maes *et al.*, 2016). The ecosystem services approach is increasingly used in work aimed at designing, optimising or improving Green Infrastructure (Andersson *et al.*, 2014; Coutts, Hahn, 2015; Escobedo *et al.*, 2019; Lovell, Taylor, 2013; Manes *et al.*, 2016). Following a previous assessment of ecosystem services performance, we selected Habitat Quality and Degradation and Carbon Stock and Storage as the main characterizing aspects related to landscape multifunctionality. Habitat Quality reflects a measure of the capacity of a territory to provide ecosystem services while considering the cumulative effect of spatially distributed threats and pressures (Terrado *et al.*, 2016). It is often used as a proxy for biodiversity and species richness and it is assumed to be meaningful for the effectiveness of conservation policies (Sallustio *et al.*, 2017) and the increasing environmental performance following the implementation of land management policies (Balletto *et al.*, 2020; Scorza *et al.*, 2020b).

Mirroring it is instead the concept of Habitat Degradation that represents the worsening of environmental performance as a result of dynamics such as infrastructuring and urban growth, increase in intensive and impoverishing

**Figure 3:** Habitat Degradation increase (adimensional), 1990-2018.
**Source:** Author's elaboration.

agricultural practices or, more generally, higher anthropic pressures (Sallustio *et al.*, 2015) (Figure 3). Carbon Stock and Storage was also considered as an essential component for characterizing alterations in ecological processes following land use changes and as a factor that is immediately perceived and thus interpretable as directly related to quality of life. It is computed as the sum of four contributions: aboveground biomass, namely all the living plant materials at the ground level, belowground mass accounting for the root system, dead litters and wood organic and soil organic carbon (Houghton, 2003).

The reasons behind the choice of these factors are twofold. On the one hand, they are strongly affected by land use changes and the transformations that occurred all over Italy during the last few decades, being directly related to the sustainability of land management policies and their effects on the ecosystems' functionality.

On the other hand, they provide a measure of the perception of the deterioration of environmental conditions in general, depending on complex dynamics and multiple factors related to adverse weather exposure, pollution, anthropic pressure and, therefore, to conditions of poor livability.

In our interpretation, therefore, they contribute together with geographical and climatic factors in determining poor environmental performance, greater vulnerability to the spread of any pathogens and in paving the way for the epidemic.

#### 2.1.2. COVID-19 and the environment

In epidemiological and health studies, there is often the need to compare death rates between different areas, taking into consideration differences in age structure and population distribution. Standardized Mortality Ratio (SMR) is used to tackle such an issue (Gatrell, Elliott, 2002). With the areal units considered, in the present case the Italian provinces as administrative and statistical units, with the age-specific rates of deaths in some wider populations, the expectation of the number of deaths is calculated. The observed values are compared to the expected deaths obtaining a value: a value of 1 indicates an expected level of mortality, higher than 1 shows a mortality higher than that expected, and values lower than 1 imply a reduced and lower than expected mortality (as described in Figure 9*c*).

For the Italian case, the adjusted SMR was calculated with reference to different moments of the virus outbreak and its spatial variability compared to other environmental, geographical and socio-demographic data and indicators (Murgante *et al.*, 2020b).

### 2.2. The Dataset

#### 2.2.1. Data collection

Data were referred to Italian provinces, an intermediate level between administrative units such as municipalities and regions. Such areal units were considered as the minimal units where data could be referred and compared, although, given their heterogeneity in terms of shape and size, they hold the risk of confusing the spatial pattern drawn by the geographical units with that of the underlying population, rather than of the phenomena under examination (Cressie, 1996; O'Sullivan, Unwin, 2010; Unwin, 1996; Openshaw, 1983). Total COVID-19 cases and death cases for Italy were considered on 30th April 2020 as reported by the Italian Ministry of Health and as collected by the Civil Defence. This moment in time represents a good compromise as portraying a «frozen» and stable situation of the COVID-19 outbreak in Italy. Italy was in fact locked down at the beginning of March, and until the end of April-beginning of May most of the economic activities and personal

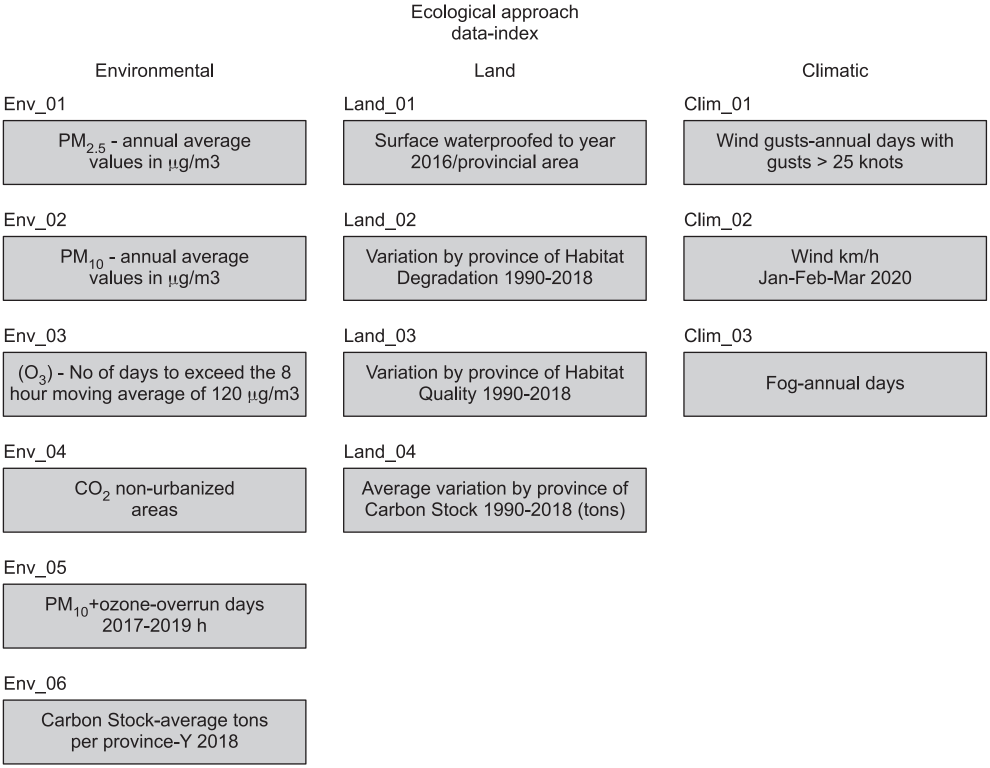


**Figure 4:** Dataset of environmental, land and climatic classes.
**Source:** Author's elaboration.

movements were dramatically reduced. The timeframe is therefore suitable for understanding the pattern. Death cases required a more in-depth and thorough analysis as they were not originally available at provincial level but only at the higher, regional level. They were used both related to population and also synthesized in a Standardized Mortality Rate in order to better relate the phenomenon to the overall age and spatial distribution of the population. Demographic and socio-economic data come from the Italian Statistical Institute (ISTAT – Istituto Nazionale di Statistica), as population, total and organized in age groups, as well as mortality, differentiated by causes, in 2019. Environmental data were taken from the Higher Institute for Environmental Protection and Research (ISPRA – Istituto superiore per la protezione e la ricerca ambientale), WHO (World Health Organization), ISS (Higher Institute of Health), EEA (European Environmental Agency), Il Sole 24 Ore, Legambiente (non-profit association for environmental protection), ACI (Italian Automobile Club), ilmeteo.com and windfinder.com (weather and wind data). We also collected data on air quality ($PM_{2.5}$, $PM_{10}$, $NH_3$, CO, $CO_2$, NOx) and weather conditions (humidity, wind, rain). A total of more than 80 different indicators at provincial level were collected for the overall research on COVID-19 in Italy. These data presented a high degree of spatial autocorrelation with significant indicators of pandemic spread and its effects on the population, in terms of contagions and death (Murgante *et al.*, 2020a). For the purposes of the present research, we selected and grouped a subset of such a big dataset.

As input data (Figure 4), the results from the ecosystem services' evaluation were considered, these same datasets that the authors built in previous research activities preparatory to this paper (Supplementary Material, Murgante *et al.*, 2020b). In particular Land 02, Land 03 and Land 04 derive from the evaluation of the performance of ecosystem services, all other data come from a previous dataset processed. The overall dataset is organized in three main categories, as Environmental, Climatic and Land.

### 2.3. Methods

In light of previous research by the same authors (Murgante *et al.*, 2020a, 2020b), we consider it proper to divide the factors contributing to the spread of the pandemic into the following three classes: Environment, Land and Climatic. As can be seen from Figure 5, the flowchart of the methodology essentially consists of two main phases. In the first, the spatial dataset was built by including the results obtained from the ecosystem services performance analysis.

At the end of this step, the final dataset is composed of

1) The outcomes from ecosystem service performance assessment:
   *a*) Variation by province of Habitat Degradation 1990-2018 (Land_02);
   *b*) Variation by province of Habitat Quality 1990-2018 (Land_03);
   *c*) Average variation by province of Carbon Stock 1990-2018 (Land_04).
2) The wide COVID-19 database:
   *a*) Environment (Env_01-Env_06);
   *b*) Climate (Clim_01-Clim_03);
   *c*) Land data (Land_01).

The second step is instead the editing of hazard maps through a spatial multi-criteria analysis performed by means of the Spatial Analytical Hierarchy Process (AHP) method (Saaty, 1980) that was meant to assign, from time to time, different priorities to the three classes of factors (Environmental, Climatic and Land). This method, widely used to approach complex decisions involving both numeric and qualitative variables, supports the formulation of different scenarios following a comparison between potential alternatives. The scientific literature is full of applications related to different areas and disciplines: from allocation of economic resources to the resolution of conflicts, to issues related to land management and planning (Celli *et al.*, 2018; Cieślak; 2019; De Marinis, Sali, 2020; Grimm *et al.*, 2008; Karlsson *et al.*, 2017; Mishra *et al.*, 2015; Saaty, 1984). The main advantage of the AHP is in fact to reduce the complexity of the decision process, allowing, however, to

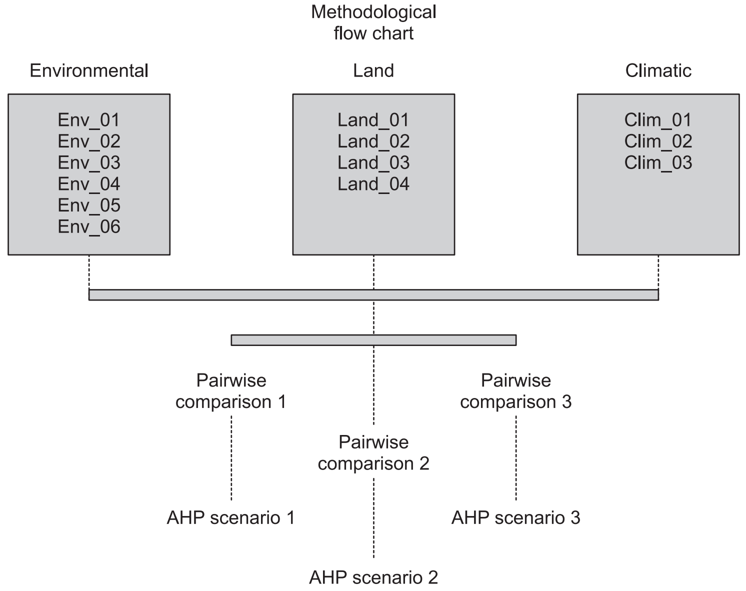


**Figure 5:** Methodological framework.
**Source:** Author's elaboration.

Scenario 1-Pairwise comparison matrix

| | Env | Land | Clim |
|---|---|---|---|
| Env | 1 | 2 | 7 |
| Land | 0.143 | 1 | 5 |
| Clim | 0.5 | 0.077 | 0.655 |

Scenario 2-Pairwise comparison matrix

| | Env | Land | Clim |
|---|---|---|---|
| Env | 1 | 3 | 0.333 |
| Land | 3 | 9 | 1 |
| Clim | 0.333 | 1 | 0.999 |

Scenario 3-Pairwise comparison matrix

| | Env | Land | Clim |
|---|---|---|---|
| Env | 1 | 0.333 | 1 |
| Land | 1 | 0.2 | 5 |
| Clim | 3 | 1 | 5 |

**Figure 6:** Pairwise comparison matrices for each of scenarios 1, 2 and 3.
**Source:** Author's elaboration.

|  | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Environmental | 0.591 | 0.231 | 0.187 |
| Land | 0.334 | 0.077 | 0.655 |
| Climatic | 0.076 | 0.692 | 0.158 |

**Figure 7:** Weights resulting from AHP.
**Source:** Author's elaboration.

check the consistency of the evaluations (Moreno-Jiménez *et al.*, 2008). The selected criteria are compared using the nine-point scale where 1 indicates equal importance, while value 9 refers to the first criterion and is highly important compared to the second one (Özdağoğlu, Özdağoğlu, 2007).

Because the purpose of this work is to compare three hazard scenarios that maximize the effects of environmental, climatic, and land management-related factors, the pairwise comparison was performed for each parameter class (Figure 6).

This allowed, following the validity assessment by means of the consistency test, the definition of the three weights' vectors (Figure 7).

## 3. Results

The results obtained consist of three hazard maps (Figure 8) representing scenarios 1, 2, and 3 which maximize the effects of environmental, climatic, and land management factors, respectively. The hazard levels were divided into 5 classes, from very low to very high, according to the Natural Breaks method that defines the thresholds from one class to another by maximizing the differences between classes while minimizing the squared deviation mean in each of them (Jenks, 1967). The use of this method is common for the classification of risk and hazard values (Golian *et al.*, 2010) obtained by multicriteria analysis (Fariza *et al.*, 2017; Febrianto *et al.*, 2016; Stefanidis, Stathis, 2013).

Comparison of the maps for the three scenarios allows considerations to be made about the weight that each class of factors assumes in determining hazard conditions. The areas classified as high risk are distributed differently depending on the scenario (and therefore the classes of factors that have a greater weight) considered. This is not true for the Po Valley area where, since all three classes of disadvantageous factors exist, a high hazard is recorded in all the scenarios elaborated. This is significant of a mix of environmental, climatic and land management related factors that

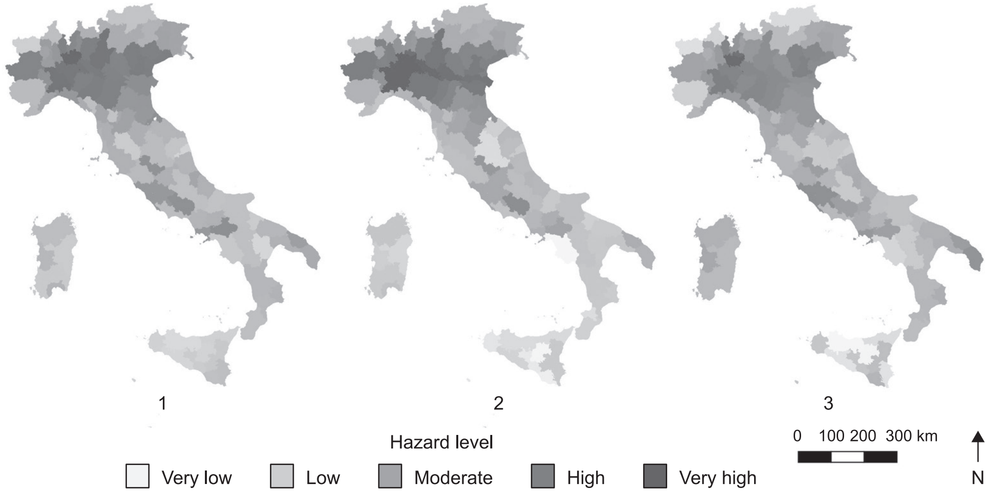


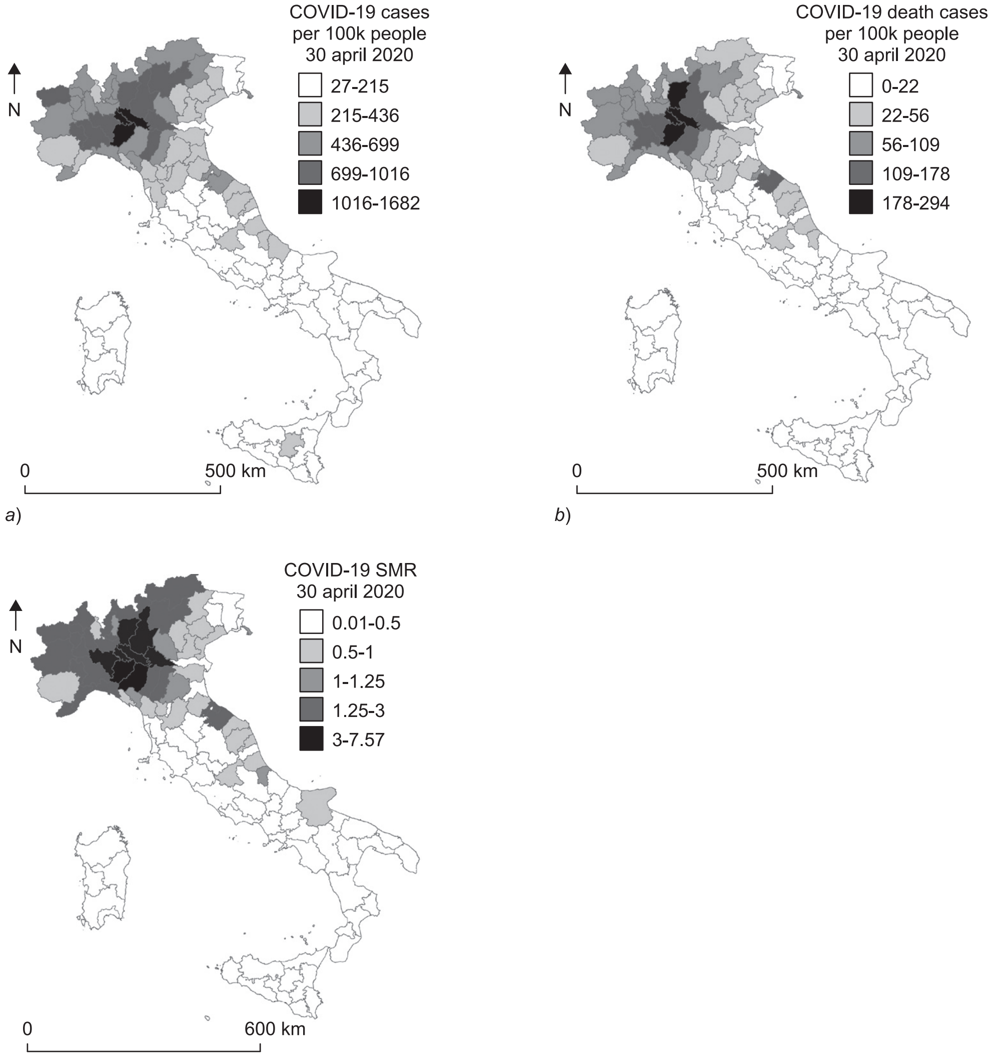
**Figure 8:** Hazard maps according to scenarios 1, 2 and 3.
**Source:** Author's elaboration.

negatively affect the pathogen spreading. Previous studies (Romano *et al.*, 2017) confirm, furthermore, the intensity of urbanization phenomena that in these areas of Northern Italy have reached significant values compared to the national context. At the same time, areas can be observed, including the two islands of Sicily and Sardinia, in which the intensity of the factors considered is such as to determine hazard conditions that do not exceed the «moderate» class.

Ultimately, when analyzing the number of provinces, the area involved and the population classified as high hazard, the second scenario – which emphasizes the role of climatic features – comes out as the most severe.

Further considerations derive from the joint analysis of hazard maps with the spatial distribution of parameters (Cases per 100k people, Death cases per 100k people, SMR; Figure 9) significant of the spread of the COVID-19. The first two maps (Figure 9*a*-9*b*) show a clustering of the number of cases and deaths mainly in Northern Italy and along the Po Valley, with extensions stretching towards the Adriatic coast and also involving other provinces along the Alpine chain. These two maps also highlight the relevant role of commuting because in the distribution of the parameters significant of pandemic spread we find correspondences with the layout of the mainland communication routes, with the metropolitan city of Milan at the top.

The SMR – Standardized Mortality Ratio (Figure 9*c*) confirms this distribution, concentrated mainly in Lombardy, Piedmont, Emilia-Romagna, Liguria, Val D'Aosta and Trentino Alto Adige, and in some provinces located along the Adriatic coast. Looking at our hazard maps and the spatial distribution of the SMR index, further matches emerge. In fact, where the



*a*) *b*) *c*)

**Figure 9:** Standardized Mortality Ratio (SMR) data at 30th April 2020.
**Source:** Author's elaboration.

SMR has its highest values (Po Valley area and Northern Italy in general), we find high hazard for all three scenarios. On the other hand, where the level in our hazard maps is «Low», an increase of the mortality rate has not been reported (SMR < 1). The opposite is not always true: there are in fact some provinces along the Alpine chain (e.g. Trento, Bolzano, Aosta), where an SMR value greater than 1 corresponds to a hazard level varying between «Very Low» and «Low».

Shifting the demographic data related to each province, it is possible to extend our considerations also to the area involved (Figure 10) and popula-

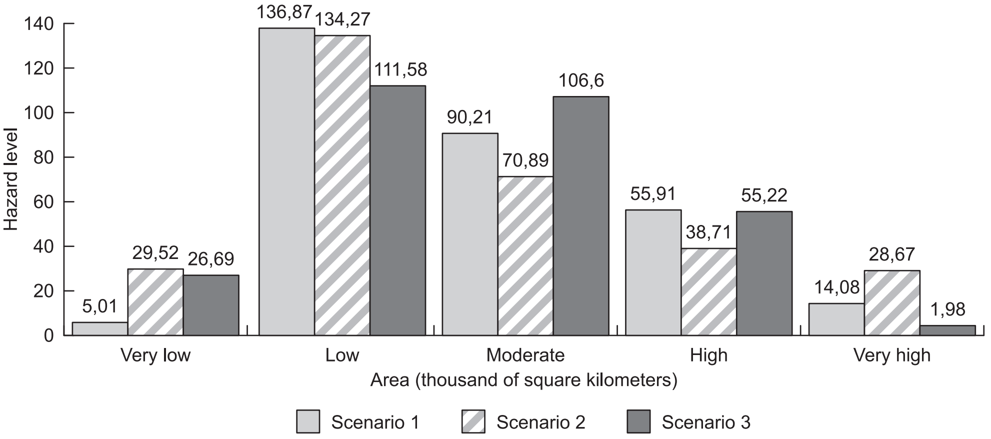


**Figure 10:** Comparison between the three scenarios in terms of areas.
**Source:** Author's elaboration.

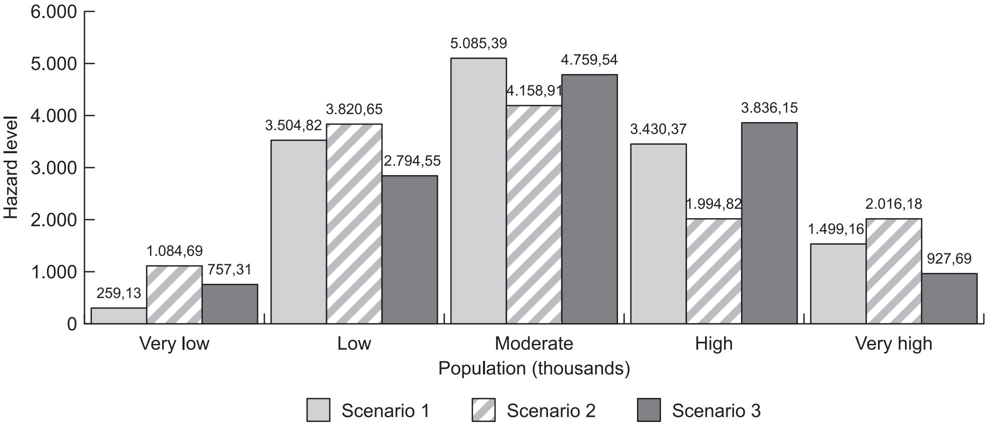


**Figure 11:** Comparison between the three scenarios in terms of population over 65.
**Source:** Author's elaboration.

tion aged over 65 (Figure 11) potentially affected by the pandemic spread according to our hazard maps. The first graph shows that most of the Italian territory is characterized by a level of hazard ranging from low to moderate while the areas classified as high and very high hazard are relatively small. This is comforting in the perspective of planning interventions and actions aimed at risk mitigation in a short period of time.

On the other hand, observing the data relative to the over-65 population, which is considered more exposed to the risks connected to the pandemic, it emerges that for all three scenarios formulated, the most populous class is that of moderate hazard. It should also be noted that Scenario 3, which

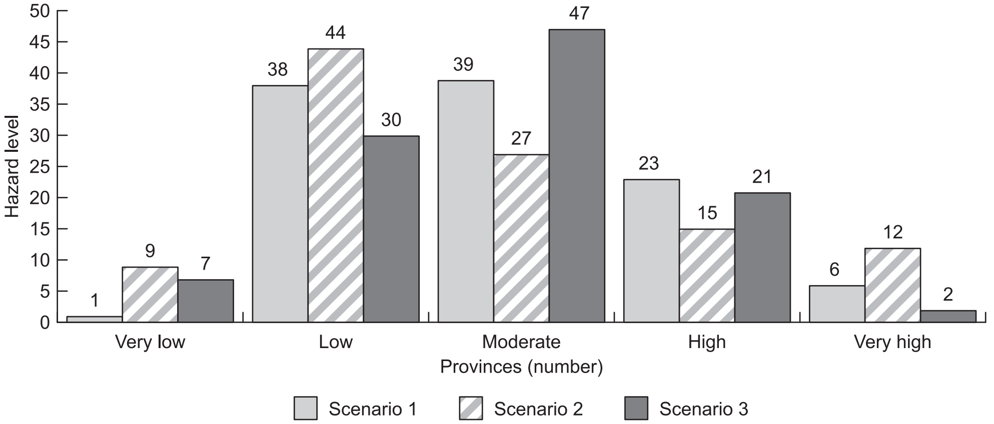


**Figure 12:** Comparison between the three scenarios in terms of number of provinces.
**Source:** Author's elaboration.

reflects the effects of land management policies, places in the highest hazard range the provinces that are not so extensive but very populous.

Comparing the hazard scenarios and the real cases (affections and deaths) observed in Italy, it is possible to notice that the areas included in the highest hazard class belong to the regions of the Po Valley and the neighbouring provinces (Lombardy, Emilia Romagna and part of Piedmont) while there are some areas, for example the Province of Rovigo, considered at high environmental risk although the real cases recorded were very few. This is probably linked to a favourable position as it is far from the main roads (Figure 12).

Moreover, our hazard maps do not explain the infections registered in some areas of the Alpine chain such as the Provinces of Trento, Bolzano and Aosta. Other areas affected by significant epidemic outbreaks were not considered to be at risk: this is the case of the Provinces of Friuli Venezia Giulia in the North-Eastern Italian sector. Although overall the region is not considered to be at risk, it has recorded a considerable number of mortality cases in the Province of Trieste and in part of the Province of Udine, probably attributable to the high concentration of rest homes and hospitals.

The resulting areas characterized by the highest hazard class include the major metropolitan areas: Milan, Turin, Verona – in the North – Bologna, Florence, Rome – in the Centre – Naples, Bari and the other major cities in the South and islands. These provinces did not present a very high impact of COVID-19 in relative terms: for example in Milan and Turin – metropolitan cities – lower relative cases than neighbouring provinces occurred. Further Northern and Central Italian provinces such as Verona, Bologna and Florence, quite close and connected to the Po Valley, a hot spot for COVID-19 outbreak, registered fewer cases. This means that environmental conditions are not enough to explain the overall risk value. Other works (Murgante *et al.*, 2020a, 2020b) showed that a minor spatial homogeneity could help understand this kind of phenomenon in terms of spatial autocorrelation.

## 4. Discussions

Our effort in this work is aimed at the drafting of hazard maps that can give a contribution to the implementation of policies useful to strengthen resilience against an extreme event such as the spread of a pandemic.

The graph in Figure 13 represents the domains of functionality and dysfunctionality of a system under two hypothetical scenarios: the business as usual scenario and the sustainable one. In the time period between T0 and T1, the system is functional, as it can satisfy the needs demanded by society.

At T1 an extreme event of intensity comparable to a global pandemic occurs: the functionality of the system decreases rapidly because, for example, the health system is not able to support the load deriving from the number of infected people.

The level of functionality decreases until the system's state moves into the dysfunctionality sector. Two possibilities arise at this point: the system collapses because it fails to react to the extreme event (dashed curve) or the reaction of the system allows a gradual resumption of the functionality and therefore a trend again in the increase of the curve (continuous line).

Defined as T2 and T3 the instants in which the state of the system is back in the functionality sector, the time span of the recovery period is different and depends on the initial state of the system and therefore on the scenario in which we are.

In fact, it is possible to observe that (T1-T2) < (T1-T3) and this means that the functionality recovery time is shorter in the case of the sustainable scenario. This scenario represents a system in which efforts – land policies, environmental investments, etc. – are planned and implemented in light of long-term goals that guarantee effective results in reducing health risks. In the case study, the sustainable scenario is therefore linked to environmental, climatic and land management factors such as pollution reduction, air quality, climate regulation, protection of ecosystem functions, land take.

Our results therefore allow us to interpret the hazard maps developed in the light of a business-as-usual scenario which, by neglecting the factors considered in the blind view of an economic development exclusively aimed at increasing productivity even at the expense of the quality of life, has contributed to create unfavourable conditions in the case of a pandemic. This shows that some paradigms of traditional spatial planning need to be revised in favour of a methodology based on performance indicators oriented towards a more holistic view of spatial components and the fostering of landscapes' multifunctionality. The importance of integrating these aspects within the various levels and at the different scales of planning is stressed

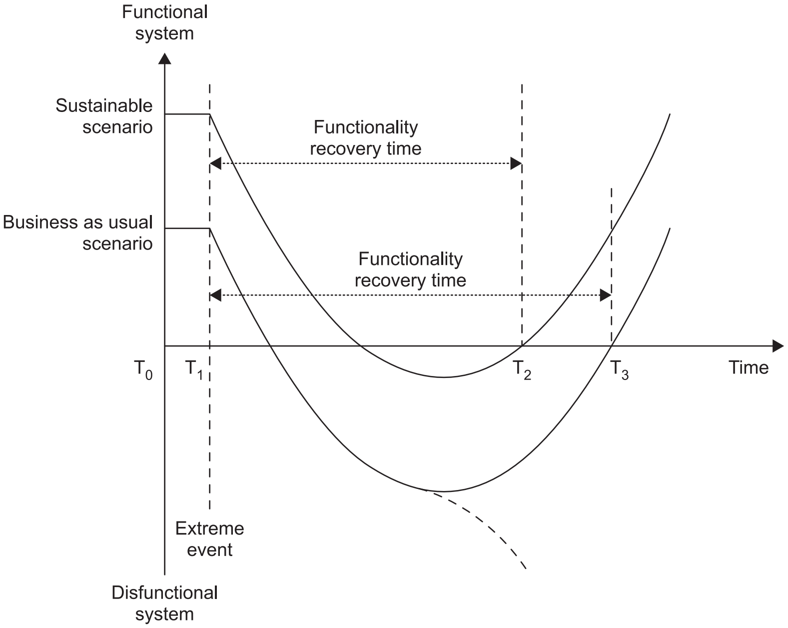


**Figure 13:** Functional and dysfunctional system.
**Source:** Author's elaboration.

by several authors (Brown, Grant, 2005; Corburn, 2004; Duhl, Sanchez, 1999; Garcia *et al.*, 2003; Nieuwenhuijsen, Khreis, 2018), even more in light of the implications that these factors have on human health and well-being (D'Alessandro *et al.*, 2017; Capolongo *et al.*, 2018).

As discussed extensively in the results, the provinces with the greatest number of COVID-19 infections and deaths are Bergamo, Brescia and Milan (Lombardy Region) and it is significant that within the Regional Urban Planning Law – Regional Law no. 12 of 2005 – of this region there is an explicit reference to the evaluation of the urban plan from a health-sanitary point of view which, although it supports decision-making by municipalities regarding the approval, the rejection or the request for further documentation (Capolongo *et al.*, 2016), it is not mandatory for approval. Our view is that if Urban Planning Law and health and wellness assessments were fully integrated, a comprehensive evaluation, such as the one proposed as part of this work, would allow direct intervention on the factors used to build hazard scenarios and thus encourage reduction in recovery time by making the system more sustainable and resilient.

The link between proper land management and aspects related to health and quality of life in urban environments should be made more operational in order to support planning procedures and provide effective tools to support decision-making processes. Although pollution-related issues are well known and investigated (Cersosimo *et al.*, 2020; De Feis *et al.*, 2020), and their proper assessment is made even more urgent by the expected climate change (Maragno *et al.*, 2020; Pasi *et al.*, 2019; Pietrapertosa *et al.*, 2019; Kovats *et al.*, 2003), the most shared opinion still interprets planning exclusively as a constraint to economic development according to the business as usual approach.

An outdated approach to planning (Romano *et al.*, 2018; Scorza *et al.*, 2020c; Scorza *et al.*, 2020b) has failed to adequately consider the effects associated with dynamics such as land take (Romano *et al.*, 2017; Romano, Zullo, 2014a, 2014b; Hanzl, 2020) and loss of ecosystem services (Hanzl, 2020; Geneletti, 2013, 2016). Several studies at the national level in Italy (Martellozzo *et al.*, 2018; Amato *et al.*, 2016) explain and analyze the negative consequences of past urban and regional planning, some (Martellozzo *et al.*, 2018) even developing forecast models to 2030 based on the two hypothetical scenarios «sustainable» and «business-as-usual».

This study also confirms that density is not a key factor in the spread of COVID-19 (Hamidi *et al.*, 2020; Paez *et al.*, 2020; Harris, 2020) and that the concepts of density and crowding are often mistakenly confused. Crowding, in fact, is related to the occurrence of events or contextual situations that are independent from the resident population and that can also take place in remote areas. With reference to the Italian case, the provinces of Northern Italy and those of the Po Valley in particular are affected, where the average population density and a high percentage of incoming and outgoing commuters means that they behave more like traffic generators than poles of attraction, as metropolitan cities in general.

## 5. Conclusions

Mapping environmental risks has allowed us to deliver and improve the territorial knowledge through numbers of specific applications, during the COVID-19 pandemic we discovered different levels of territorial vulnerability deriving from progressive weakening of territorial structures – i.e., public health services – compared with ineffective environmental policies and sustainable land management policies.

The hazard maps proposed in this study are a representation of disparities assessed in Italian cases leading to different territorial responses to the pandemic. The environmental components play an important role in defining the red hazard zone. This should reinforce the awareness that a renewed sustainable development strategy has to be finally prepared, not only with the objective of recovering from the socio-economic gaps produced by COVID-19 but mainly to put into action a collaborative effort to make people and the territorial system resilient in front of the environmental, climatic and health shock.

The possibility to compare hazard maps related to scenarios that maximize different factors allows the decision maker to orient policies towards different priorities, according to a place-based approach capable of satisfying sustainability principles from multiple points of view. In particular, guaranteeing transparency which is in fact a necessary prerequisite for the success of health surveillance, as well as minimizing damage. In fact, in a pandemic, restrictions on individual freedom and the imposition of infection containment practices may be necessary to protect citizens' health. In this regard it is important to consider that the restrictions imposed by the lockdown have drastically reduced production activities and consequently air pollution, an important factor in preventing the collapse of the system (dashed curve in Figure 13) and therefore its recovery, environmental protection and pollution prevention could be very useful for modulating the level of restrictions to be imposed in the event of a pandemic. These restrictions can be better scientifically motivated and therefore explained explicitly by the political decision-makers thanks to the proposed method that allows a geospatial representation of the risks. Environmental, territorial and climatic conditions change from province to province, from region to region and facing a new possible phase of spread of the epidemic requires a renewed risk approach that takes into account the characteristics of the contexts. Finally, the risk map highlights the relationship of infections and population density, but it is not the same for lethality, which instead depends on numerous factors including geo-environmental conditions.

Future developments will concern the proposal of a risk map that could be realized by integrating into the present proposed methodological framework, demographic and pathology data in order to understand the vulnerability at the local level, considering co-morbidities aggravated by COVID-19, at present not easily detected and classified by the scientific community.

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