Article

Why Italy First? Health, Geographical and Planning aspects of the Covid-19 outbreak

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Abstract: The Covid-19 has hit Italy in February 2020 after its outbreak in China at the beginning of January. But why Italy first among Western countries? What are the conditions that made Italy more vulnerable and the first target of such disease? What characteristics and what diffusion patterns could be highlighted and hypothesized, from the outbreak to the end of March 2020, after containment measures - including a national lock down – were introduced? In this paper we try to provide some answers to these questions, analyzing the issue from the medical, geographical and planning points of view. In particular, we started from a hypothesis of very similar economic, geographical, climatic and environmental conditions of the areas of Wuhan – in Hubei Province in China, the outbreak of the epidemics – and the Po Valley area – in Italy – where most cases and deaths were registered. Adopting an ecological approach, we compared the spatial distribution and pattern of Covid-19-related mortality in Italy with several geographical, environmental and socio-economic variables at Provincial level, analyzing them by means of spatial analytical techniques as LISA – Local Indicators of Spatial Association. Possible evidence relating Covid-19 cases and Nitrogen-related pollutants and land take arise, particularly in the Po Valley area.

Keywords: Covid-19; Italy; Po-Valley; NOx; Pollution; Particles; Land Take; Spatial Diffusion Processes; LISA.

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1. Introduction

1.1. Why Italy (1)? The epidemiologic point of view

In December 2019, in the Wuhan province of China, a new Coronavirus emerged following a spillover; this RNA virus was roughly 80% homogenous with the SARS virus, hence the name SARS-Cov-2 (Severe Acute Respiratory Syndrome Coronavirus 2) [1]. This led to a wide-reaching epidemic of a new respiratory disease (Covid-19), which, within one quarter, had crossed the borders of Asia becoming a pandemic with over 2,300,000 cases and 160,000 deaths as of April 21, 2020 [2].

The disease is spread via interhuman transmission, through Flugge's droplets, although it is also airborne if aerosols are generated and, as with normal influenza, it can also be transmitted indirectly via the hands or fomites [3] [4] [5]. Its onset, following an average incubation period of 5-6 days (range 2-14 days), is acute and characterized by fever, headache, sore throat, dry cough, runny nose, muscle pain and sometimes gastrointestinal symptoms [2][3]. It has a similar course to influenza, generally in a mild or moderate form, particularly in young subjects and in those who have no comorbidities [5].

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It has recently been shown that the disease is contagious even before the onset of symptoms, also in asymptomatic subjects, with a reproducibility rate of R_0=2,6 [3]. Severity, and thus fatality, increases with age. Fatality, excluding for rare fulminant forms, generally follows serious pictures of Covid-19 that present with interstitial pneumonia, on average around 7 days from onset, some of which go on to develop a critical clinical picture with respiratory failure, after approximately 9-10 days, which in turn may be followed by septic shock and multi-organ collapse [5] [6]. The most frequent clinical presentation leading to a lethal outcome is interstitial pneumonia. The case fatality rates from Covid-19 nationwide generally appear higher than those observed in other European countries and in China. In particular, from a rapid processing of the data recently reported by the Italian Higher Institute of Health Care *(ISS - Istituto Superiore della Sanità)* [5], the area including some municipalities of the Po Valley in the territories of Lombardy and Emilia Romagna shows significantly higher case fatality rates -11.3 % vs 4.5%; p <0.001- compared to the rest of Italy. This figure may underlie a real increased risk of complicated interstitial pneumonia in these territories or it could be the effect of bias. In fact, case fatality rates currently available for Italy are undoubtedly overestimated, compared to what was observed in China, as the denominator - number of positive subjects - is derived from diagnostic tests that are mainly carried out on symptomatic individuals. Another possible source of the overestimation of the data stems from the classification of deaths, which in our country are entirely attributed to Covid-19 even when patients present with severe comorbidities [5].

However, to date it is evident, as recently highlighted by a study conducted by the Cattaneo Institute [7], that there is a tendency in Italy for higher mortality rates thereby prompting consideration of all possible hypotheses regarding this trend. In particular, some plausible explanations proposed consider certain intrinsic characteristics of the population. On the one hand, Italy has an older population on average and is thus exposed to a higher risk of complications of the disease [8]. Despite this, this data alone cannot explain such a marked difference in the distribution of cases compared to other national, European and foreign realities. Moreover, the literature does not report any genetic drift typical of the populations most affected by epidemic outbreaks that could explain the current situation.

A further possible explanation can be ascribed to the presence of comorbidities that older people clearly possess [9]. Even this phenomenon, however, is not exclusively observed in the Italian population, therefore it does not currently constitute a certain determinant. In addition, one derived hypothesis relates to the possible greater prevalence of the use of some drugs that induce the cell expression of receptors for the virus [10]. For example, one current theory that seems quite appealing regards the possibility that the chronic use of RAS blockers antihypertensives such as sartan, inducing by biochemical feedback a hyper-expression of the ACE-2 enzyme which is used by the virus as a receptor, could explain the worsening of pneumonia following intubation, since the suspension of the drug orally would make the virus receptor available, that is because RAS blockers should not be discontinued [11]. The link between hypertension and lethality had already been observed in China, but recent Italian data reported by the ISS [5] show that about 70% of fatal cases occurred in hypertensive subjects. However, even if these differences in the use of medications may explain international differences, it seems unlikely that significant differences should be observed between different zones of the same country. This hypothesis must currently be validated and will be subject to further analytical epidemiological studies and scientific investigations.

The hypothesis has also been put forward that the virus circulating in the national territory has mutated, acquiring greater virulence and pathogenicity. Scholars, however, disagree with this claim, and continue to strongly argue that the circulating strain is in fact the German one that gave rise to the spread in Europe [12].

To date, therefore, the hypotheses have focused on the one hand on a possible greater reproducibility of the virus, that is on the determinants that constitute R_0, and on the other, on a greater likelihood of encountering hyperergic forms due to the combined or predisposing action of other determinants. As far as reproducibility is concerned, knowing that $R_0 = \beta CD$ (β = probability of transmission per single contact, C = number of efficient contacts per unit of time and D = duration of the infectious period), an evaluation must be made, bearing in mind the possible existence both of super spreaders, and of those purely environmental conditions, which by inversely influencing the half-life of the viral load, favor the duration of virus infectivity in the environment with a consequent greater transmissibility [13][14]. This fact could lead to such a sudden increase in cases that healthcare facilities would be unable to deal with all cases, rather the more serious ones would be diagnosed mainly with the consequence of observing an apparent greater lethality due to their natural evolution.

As regards the possibility of a predisposition towards developing hyperergic forms, which can lead to greater lethality, some observations always focus attention on environmental factors in areas such as the Po Valley, territories connected by a dense transport network and industrial activity which are constantly characterized by the presence of strong concentrations of environmental (and atmospheric) pollutants. In particular, the scientific panorama has already demonstrated the existence of significant correlations between high concentrations of atmospheric particulate matter and greater spread of some pathogenic microorganisms, such as the measles virus [14].

Moreover, the constant exposure to atmospheric pollutants above the alert threshold may also explain a condition of basal inflammation that can afflict populations, altering the physiological conditions and leading to a greater predisposition to infection and symptomatic development of the disease [15] [16].

1.2. Why Italy (2)? The spatial point of view

The conditions for a pandemic spread depend primarily on the possibility that the virus has to escape from the territory in which the epidemic broke out and hence on its ability to spread.

Therefore, the type of social, cultural, economic and commercial relations with China and hence the movement of people to and from that country can explain both the possibility of virus penetration and the intensity of risk of generating multiple epidemic outbreaks. As already happened for SARS, for which the first important way of contagion and international diffusion was a meeting held in Hong Kong at the Hotel Metropole, in the same way for SARS-Cov2 it is known that one meeting held in a luxury hotel in mid-January in Singapore spawned several coronavirus cases around the world. More than 100 people attended the sales conference, including some from China [17]. We know that from here the virus has penetrated in Europe in France and in Great Britain first, and that Italian transmission arose in the Po Valley as secondary cases generated from the case zero in Germany [12]. Therefore, the epidemic should have spread first in those countries before than in Italy

Why Italy first? Italy has been seriously hit, one of the most important case in terms of death toll out of Hubei Province and mainland China, in the world, making it a 'pioneer' in the epidemic concentration and diffusion, with a relevance of the phenomenon early outnumbering the China's 'neighbor' South Korea. Several questions arose in terms of the geographical reasons of the spreading, of its concentrations and on the pattern drawn at different scales and involving the different Italian regions and provinces. Following are some comments and reflections, related to the global and local aspects of the phenomenon, particularly arising after the first outbreak of the phenomenon and its dramatic spreading in Western countries, in Italy in particular. A second - and third, nested - question arose in terms of why Northern Italy first and why with such strength in terms of virulence, spreading particularly in part of the Po Valley region and - apparently - sparing a huge part of Central Italy and most of Southern Italy.

We started observing some elements of similarities between some of the areas of the most severe spreading of the disease, as Wuhan in the Hubei province in China and the Po Valley in Italy, including in particular the Great Milan Metropolis and major industrial cities.

The first suggestions came from ESA maps [18] [19] of pollution displaying the most concentrated areas of presence of NO_2, where we could spot, among the others, Wuhan urban agglomeration and the Po valley. We therefore wanted to investigate the similarities of the two mega urban agglomerations, in terms of the physical and human geographical, climatic and functional characteristics. In particular, we aimed at investigating the role of air pollutants in relation to the main urban centers affected by the Covid-19. In fact, as recently pointed out by Conticini et al [16], a prolonged exposition to air pollution represents a well-known cause of inflammation, which could lead to an innate immune system hyper-activation, even in young healthy subjects. Thus, living in an area with high levels of pollutants could led a subject to being more prone to develop chronic respiratory conditions and consequently suitable to any infective agent.

Although it could appear ambitious comparing Italian and Chinese situations, we observed some similarities between the Wuhan area in Hubei Province and Po Valley - Greater Milan metropolis in Italy. As the Chinese lockdown was introduced quite early, therefore isolating the different provinces, such comparison appear possible in these terms. Some of the characters of the two mega urban agglomerations are summarized in Figure 1.

Figure 1. Synthetic comparison scheme Wuhan urban agglomeration and Great Milan metropolis. Authors elaboration from ISTAT, BECK, Hylke E. et al. (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data and https://worldpopulationreview.com

Some similarities can be found in terms of dimensions of the Province of Hubei - 58.52 million inhabitants (2015) and 158,000 sq km - and that of Italy - 60,359,546 million inhabitants and 302,072.84 sq km. Although it is not easy to compare the two mega urbanized areas of about 9 - 10 million population, it is however possible to trace geo-climatic similarities, as well as those concerning human activities. In particular, both areas correspond to Cfa subclass - in Köppen climate classification system [20] - as 'humid subtropical', typical of temperate continental areas. Both are located in an alluvial plain, Wuhan urban agglomeration - Yangtze river and Great Milan metropolis - Po river.

With reference to long range transport connections, the Wuhan urban agglomeration is the most important hub in central China at the crossroads of corridors connecting Northern and Southern China [21] as well as internal China and the coast; also Chinese national highways cross in Wuhan, as well as the Shanghai–Chengdu and Beijing–Hong Kong–Macau expressways [22]; it lays also at the centre of the Beijing-Wuhan-Guangzhou line, Chinese most important High Speed Railway. Finally the Wuhan urban agglomeration hosts the international airport of Wuhan Tianhe, moving around 25 million passengers in 2018, the major hub of central China, with direct connections in mainland China, Western Europe - among these Rome in Italy and London in the UK - and USA -among other countries).

Great Milan metropolis represents the most important urban and industrial agglomeration in Italy and as a connection to Central and Northern Europe. Main Italian national highways cross in Milan, the West - East Turin - Trieste and the North - South Milan - Naples Expressways. Also national and international High Speed Railways meet in Milan, connecting the area with major European Cities and linking it to the national major metropolitan areas. Finally the Great Milan metropolis hosts the international airport of Linate, Malpensa and Bergamo, moving 49.3 millions passengers in 2019, the second major hub system of Italy, with direct connections to Europe, China, USA [23].

Both mega urbanizations have industrial and post industrial functions, with a heavy presence of manufacturing companies, in machinery, automotive and ICT, as well as advanced and cultural services, particularly in the major centres. Both the areas share a strong promiscuity with agricultural activities and a wide progression of the sprawl [24] [25] [26] [27].

In this complex international framework our work develops, which does not pretend to be exhaustive, but to show the first results.

1.3. Air quality

In trying to trace if and in which terms a constant and prolonged exposure to air pollution, as peaks of concentration of fine dust and other pollutants, constitute a pejorative factor in cases of epidemics Covid-19 [28], we paid particular attention to the relationship between climate and air quality [29].

All anthropic activities generate emission of gaseous and particulate pollutants that modify the composition of the atmosphere. Air quality and climate change are two closely related environmental issues [30]. Climate changes on the one hand affect the atmospheric processes and on the other cause changes in the functioning of terrestrial and marine ecosystems which can, in turn, affect the atmospheric processes [31]. However, these two environmental emergencies are still considered separately both at the level of the scientific community and those responsible for environmental policies, as in the case of the recent Covid-19 emergency [28]. For this reason, policies to improve air quality and to mitigate climate change must necessarily be integrated. here are options that favor one of the two aspects, worsening the situation of the other (win-lose policies). Coordinated actions that take due account of the connections between air quality and climate change constitute the best strategy in terms of economic and social costs (win-win policies) [32]. According to the EEA - European Environmental Agency - although air pollution [33] affects the whole population - collective health costs - only a part is more exposed [34] to individual risks [35] [36] [37].

In this sense, although the air pollutant containment measures [38] deriving from the numerous urban initiatives - smart building, mobility and industry 4.0 - are particularly important, the megatrend of the globalization of industrial and agricultural production with related post-industrial lifestyles shows that it is not aligned with the green energy production, circular economy and ecosystem services. In particular, Greater Milan metropolis - Po Valley - represents the outcome of industrial and agricultural globalization in Italy which presents an increasingly critical quality of air [25]. Although in the last decade in Italy there have been tax incentive measures for the purchase or improvement of the ecological performance of home heating [39] and public and private road vehicles however, the levels of air pollution for 150 days (2018) [40] have exceeded EU regulatory limits - much lower than WHO ones. Furthermore, this situation is prolonged in time as high level of air pollution and concentration of pollutants in the air have been constantly reported in the previous years [40]. In addition, it is also necessary to remember how the climatic and geographical 'handicap effect' of Greater Milan metropolis, is not secondary in the quality of the air. In summary, mega urban agglomerations [41] such as the great of Milan metropolis air pollution [42] [43] contributes to

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climatic variations although there are many synergies but also points of conflict between air quality policies - climate and urban territorial policies.

2. Materials, Data and Methods

2.1. Materials

2.1.1. The study area (Italy)

The analysis regards Italy as the area where the outbreak of Covid-19 is analyzed. Italy is located in the Southern part of the European peninsula, in the Mediterranean Sea, facing the main Seas as the Tyrrhenian, Ionian and Adriatic, located within the coordinates 47° 04′ 22″ N 6° 37′ 32″ E; 35° 29′ 24″ N 18° 31′ 18″ E. It holds mostly a temperate climate, with, mainly, dry, hot or warm summers on the Tyrrhenian coasts and Southern regions - islands included - , with no dry season with hot or warm summers on the Po Valley and part of the Adriatic coast. Cold climate, with no dry season and cold or warm summers in the major mountain chains, as in the Alps and Apennines. Bordering countries, from West to East, are France, Switzerland, Austria, Slovenia and Croatia - maritime border. Italy covers a surface of 302,072.84 sq km and hosts a population of 60,359,546 inhabitants (ISTAT, 2019) for an average population density of 200 inhabitants per square kilometer. From the administrative point of view, Italy is organized in 20 Regions - one of them, Trentino Alto Adige, organized in 2 Autonomous Provinces with regional competences. A uncompleted reform of the intermediate administrative level, led to the institution of 14 Metropolitan Cities (Ref. L. No. 56 of April 7, 2014) and provinces. Such level remains however for statistical data collection purposes (Fig. 2).

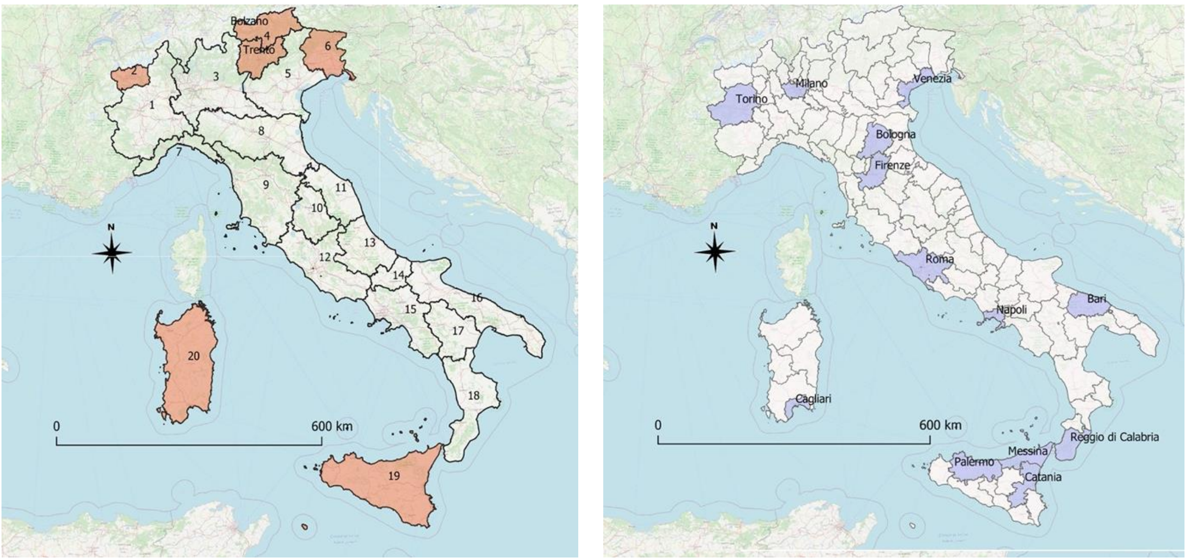

Figure 2. Italy and its administrative units. Regions : 1 – Piedmont; 2 - Aosta Valley*; 3 – Lombardy; 4 – Trentino Alto Adige* (Autonomous Provinces of Trento and Bolzano); 5 – Veneto; 6 – Friuli Venezia Giulia*; 7 – Liguria; 8 – Emilia Romagna; 9 – Toscana; 10 – Umbria; 11 – Marche; 12 – Lazio; 13 – Abruzzi; 14 – Molise; 15 – Campania; 16 – Puglia; 17 – Basilicata; 18 – Calabria; 19 – Sicilia*; 20 – Sardegna*. (* Regions with special status). Provinces and Metropolitan Cities (administrative units that substituted the homologous Provinces after 2015). Data Source: Base Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org; Administrative base map Istat (https://www.istat.it/it/archivio/222527).

Most of the population is concentrated in the Po Valley geographical region, surrounded by the Alpine and Apennine mountains and by the Adriatic Sea, Eastwards towards the Po Delta. The Po Valley alone represents Italy's economic 'core'. In an area of approximately 55,000 km^2 nearly 22 million people live, with a density - 400 inhabitants per km^2 - double than that of the rest of the peninsula, reaching different peaks in the main urban areas of the Greater Milan metropolis - the

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neighboring Milan and Monza Provinces exceed 2000 inhabitants per square kilometer. It is to be noticed that the former 'Province of Milan' become in 2015 the Metropolitan City of Milan, actually covering the same area and therefore the same municipalities of the former qualification. From a functional point of view, as it generally happen with metropolitan areas worldwide, the 'Greater Milan Metropolitan', can be considered as a wider area covering the Milan neighboring provinces of Varese, Como, Lecco, Monza - Brianza, Pavia, Lodi and Cremona: extended interpretations of the concept involve also other provinces as Bergamo, Brescia in Lombardy, and other ones belonging administratively to other regions, like Novara - hosting Milan - Malpensa international Airport - and Alessandria in Piedmont and Piacenza in Emilia Romagna (Fig. 3).

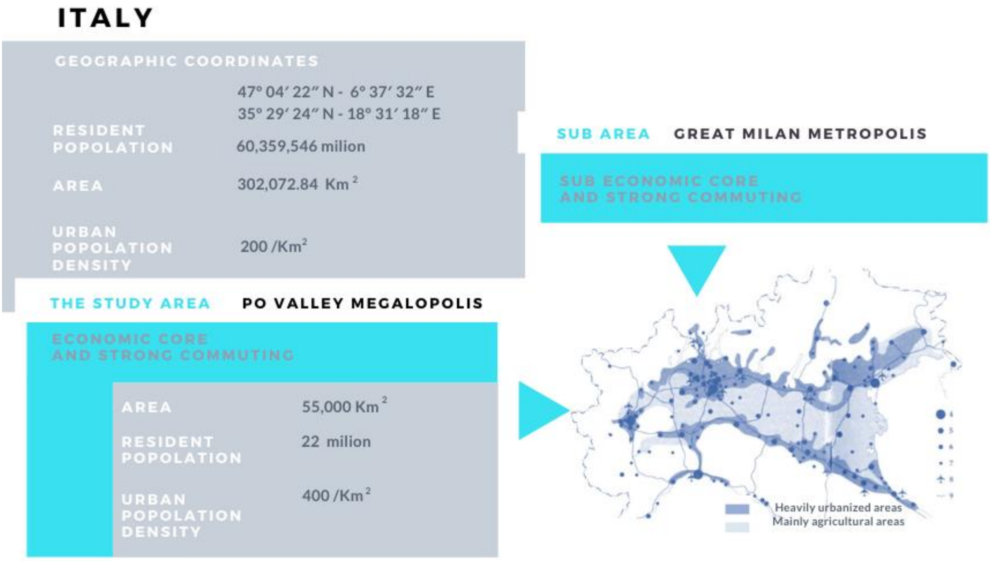

Figure 3. Main characteristics of the Po Valley megalopolis in Italy: Authors elaborations from STAT data (2019); Turri, 2003.

Milan area is the offset center of the Po Valley Megalopolis, an urbanized and industrialized area including the major Northern Italian cities - from the Western former 'industrial triangle' of Milan, Genoa and Turin - towards East to Venice and South East to Bologna and beyond, on the Adriatic Coast [44]. A high level of mobility is present in the area, both within the same area, as commuters crowd roads and railway lines, and in terms of the national and international connections, allowed by the presence of international airports, major motorways and HSR with fast services towards major national urban destinations. Such area is also the Southern part of the image of the 'Blue Banana' (Reclus, 1989), an area, stretching in the fruit-like shape from Northern Italy through Germany, North Eastern France Benelux and Southern England, as the urban, economic and industrial core of Europe (References on Italian landscape and Po Valley area: [45] [46] [47] [48] [49] [50] [51] [52] [53]. In this complex of urban and territorial dynamics of the Po Valley Megalopolis it is possible to distinguish a geo-spatial correspondence between population density and emissions of NO_2 which compromise air quality (Fig. 4).

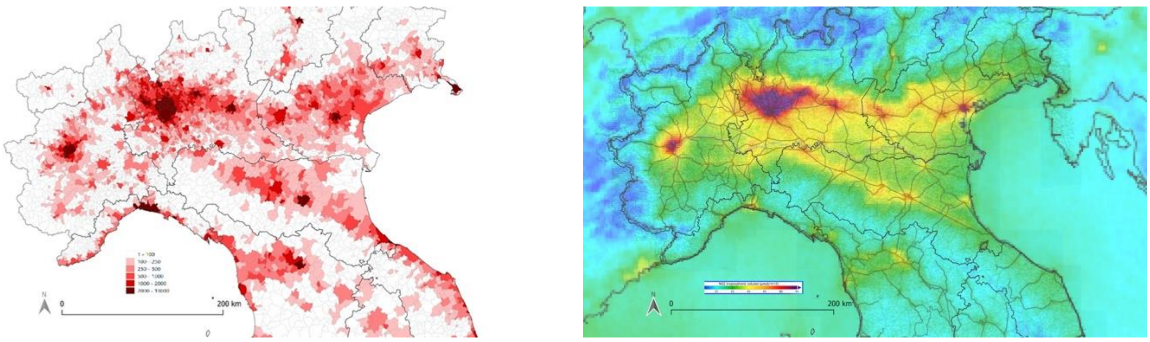

Figure 4 Po Valley. Regions, railway lines and pollution map; Po Valley Megalopolis. Source: a) Population density (Population/ km^2; ISTAT, 2019; b) ESA Nitrogen Pollution Map; ISTAT (Regions); DeAgostini Base map (source: Geoportale Nazionale)

However, the issue is much more complex because the variables involved are manifold and aspects such as the scale of investigation - wind, relative humidity, more generally weather and climate conditions - and all air pollutants must be considered. A particular case is given by the PM10 which during the lockdown has exceeded the limits in numerous units of the Po Valley megalopolis [54] [55].

2.1.2. Land take phenomenon in Italy

During the last fifty years the phenomenon of land take [56] heavily occurred in Italy in different forms, in various areas [57] [58] [59] [24]. In particular, in proximity of metropolitan and production areas, the phenomenon is more intense and it takes the form of urban sprawl: new low density settlements, with poor services and connections, added to the city, where people have the sensation to live in a more natural context. Main drivers of this trend are the spatial configuration and the attractivity of areas. When space is characterized by a homogeneous and isotropic form, the phenomenon of sprawl is more elevated. Also, socio-economic indicators play an important role in attracting people, such as new residents or commuters, generating the building of new neighborhoods or transport infrastructures. Following this model of urban growth, the soil loses its biological value, becoming unable to absorb and filter rainwater, producing negative effects on biodiversity, as well as on agricultural production [60] [61] [62]. This sealing process produces the loss of natural ecosystem functions generating a complete soil degradation [63] [64] [65] [66]. Soil is the place of energy and substance exchange with other environmental elements. The soil role in hydrogeological cycle is very important. Solar radiation causes the evaporation of water from accumulation areas towards the atmosphere. The steam rises at high altitude, cools and condenses forming clouds. The water then returns to the emerged lands in form of precipitation, a part falls into the rivers and the surface water network, another is absorbed by the soil reaching groundwater. The soil controls the flow of surface water and regulates its absorption by filtering polluting substances. The infiltration also depends on the permeability and porosity of soil.

The soil is also fundamental in the carbon cycle. Carbon is everywhere in nature and it is transformed into oxygen through photosynthesis in the carbon cycle. Through the plants, soil absorbs carbon dioxide, which can remain underground for thousands of years, feeding the soil microorganisms. Consequently, the soil is a sort of absorption well where CO_2 sequestration and storage is possible. Poor soil management can generate a loss of these properties producing negative effects [67]. Soil and related ecosystem services are important elements in the improvement of air quality reducing PM10 and O_3 [68] [69].

Another model of land take occurred in Italy in more remote zones, less accessible and mostly located in mountainous or hilly areas [70]. This uncontrolled urban development has been defined as sprinkling [71] [72]. Unlike urban sprawl, sprinkling is characterized by low density settlements, more spontaneous, dispersed and chaotic development. The cost of sprinkling is higher than sprawl [73] [74] because this model needs a lot of small infrastructures for transport, electricity, water distribution etc.. If on one side sprawl is denser than sprinkling educing depauperation of landscape, on the other side this development creates more sealing of soils, generating the total loss of its natural properties.

2.1.3. Geography of Diffusion

2.1.3.1. Diffusion processes in Geography. Some theory

A virus outbreak is a typical, still dramatic and frightening, case of spatial diffusion, a topic well known and studied in geography and dealing with its fundamentals. Diffusion in geography implies the movement of an event or set of events in space and time, and brings with itself the idea of

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a process, and the drawing of a pattern, as the outcome of the events' movement in space and time [75] [76] [77] [78]. Diffusion has been studied in geography with reference to very different sets of cases and situations, from plagues to financial crisis, from migration to music styles, from physical geography to human and economic geography. The analysis of these phenomena, realized by authors in several different contexts, brought some basic elements to be resumed.

A first categorization of spatial diffusion can distinguish cases between relocation and expansion. Relocation implies the physical movement and abandonment of the site of origin of the event, to be moved towards the new one. Expansion implies the spatial and temporal extension of a given state, or event, to cover and fill (all of) the available space (Fig.5).

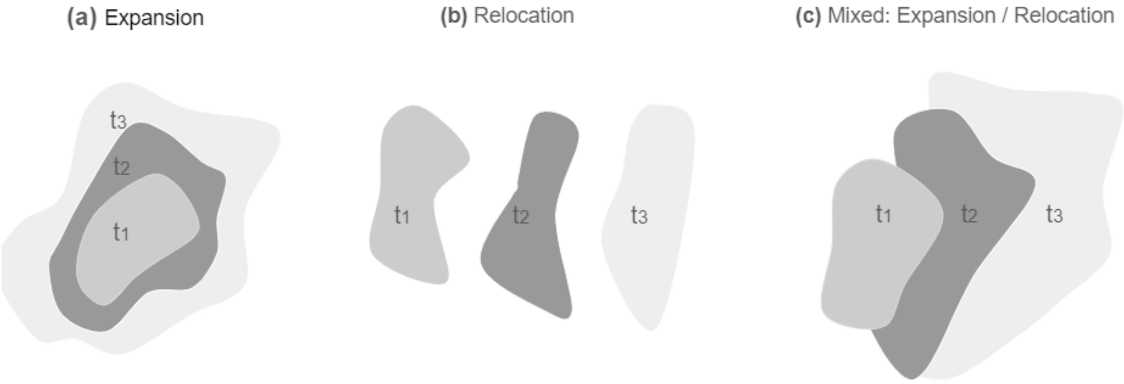

Figure 5. Types of Spatial Diffusion Process.Expansion, Relocation, Mixed. Authors elaboration from Haggett, 2001.

Expansion process can proceed in different ways and formats, and following different rules: contagion, network, hierarchical, waterfall. Contagion is the typical 'local' process that implies a contact between the event carrying the 'innovation' and those yet non-affected. The network diffusion process deals with the network structure of contact between subjects - involved in the diffusion - at local and global levels. Locally it implies the existence of social networks between people, also, locally and globally, involves the presence of major transport infrastructure and networks - i.e., transit systems locally; major air transport routes globally [79]. The hierarchical expansion process happens when the innovation is spread by means of privileged channels of communication and between centers of higher importance. Major transport and communication routes helps channeling the spreading of the innovation in space and time. Waterfall implies the direction and speed of the diffusion in such way: it is generally fast following a top-down approach -i.e., from major centers to minor ones- and slow when it moves from lower centers towards upper ones, in a bottom up approach (Fig. 6).

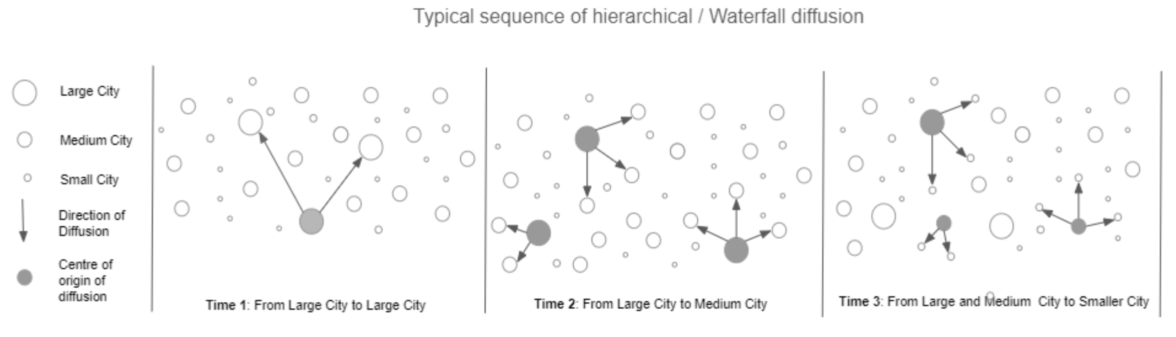

Figure 6 Types of Expansion Spatial Diffusion Process. Hierarchical / Waterfall. Authors elaboration from Haggett, 2001.

Obviously, when the innovation reaches a higher centre, it will start the fast top-down diffusion. (Fig. 7).

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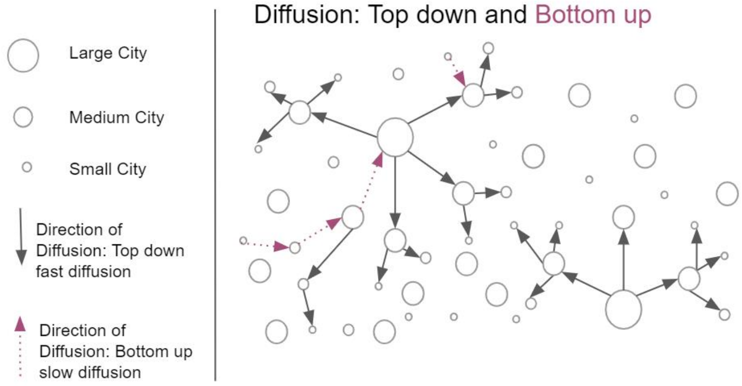

Figure 7. Hierarchical Spatial Diffusion Process: Top Down and Bottom Up. Authors elaboration from Haggett, 2001.

2.1.3.2. Covid-19 Theory and practice

The virus and disease diffusion is possibly behaving according to a mix of the above mentioned ways of diffusion. Also, Haggett and Cliff [80] recalls as diffusion processes happen as spatial diffusion waves, starting either in a single or a set of locations and then spreading out through different processes, covering wider areas.

Haggett and Cliff [81] [82] [83], also with Smallman-Raynor [84] [83] [85] among geographers, modelled such diffusion modes, examining also the relation of epidemics in space and time and the wave-nature of epidemics.

The diffusion process is a mix of expansion and relocation process: usually the epidemic starts in a given region expanding in space, and relocation occurs when its footprint fades in the place of origin and continues to grow in newly affected areas. Also, the process is contagious, when the virus spreads through direct contacts, network, as it follows networks of relations and flows between individuals and places, hierarchical, as major centres affect a higher number of lower order centres, and waterfall as the movement is generally stronger between centres following a top-down approach. The 'wave' reverses also its direction as population recovers and early infected regions go back to a cleared situation [86] [87]. In geographical terms, a diffusion wave follows - generally and theoretically, 5-steps, (Fig. 8).

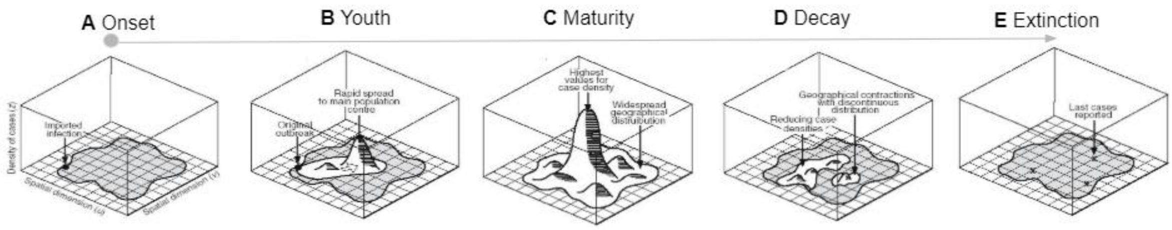

Figure 8. Epidemic wave. Authors elaboration from Cliff AD, Haggett P. A swash-backwash model of the single epidemic wave. J Geogr Syst. 2006

A. Onset: The 'innovation', as a new virus, enters "into a new area with a susceptible population which is open to infection". Typically, a single location - or a set of limited locations - is involved.
B. Youth: In this step the infection spreads rapidly from its original area to main population centres. Evidences for past outbreaks lead to highlight both local diffusion (contagion) and longer range ones (hierarchical, cascade).

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C. Maturity: The highest intensity is reached with clusters spread over a susceptible population - the whole areas involved in the epidemics. The intensity is maximum with contrasts in infection density in different sub-regions.
D. Decay: Fewer reported cases and decline is registered, with a spatial contraction slower than the proper diffusion steps. Low intensity infected areas appear as scattered.
E. Extinction: The tail of the epidemic wave can be spotted through few and scattered cases, that can be found mostly in less accessible areas.

The data available so far related to the Covid-19 virus are yet to be fully validated and understood and, at international and national level, allow only a limited possibility of analysis and understanding of the phenomena at stake and under the process of change in time and space. In trying to apply the geographical categories to the phenomenon from its roots and the beginning of the outbreak, we can observe that the contagion, as a diffusion process, is the character of the local ones, that can be observed both in the place of origin – i.e., Wuhan city and Hubei region – as well as that taking place at the different local scales – i.e., South Korea and other neighboring countries at the beginning of the phenomenon; Italy and other Western countries in the next stages. On medium and long distances – but also on shorter ones, as it will be visible in the next examples – diffusion is based on long transport networks, as rail - High Speed Trains - and air routes, and on shorter ones, as rail - regional ones - and maritime - i.e., ferry - routes.

While the diffusion takes place locally following a contagious model, a hierarchical diffusion is responsible for the regional and international diffusion of the disease. Not surprisingly, the neighboring South Korea has been the first major country affected, followed, in some weeks time, by a Western country, as Italy, and then to other European and North American countries in the following weeks. Recent studies as that of Tatem et al. [88], Ben-Zion et al [89], Bowen and Laroe [90] and, particularly, that of Brokmann and Helbing [91] on the SARS and swine flu diseases, show the network geometry of the transport system – namely air transport – as the backbone for the human interactions at global scale and also as the backbone for a virus outbreak diffusion out of its region of origin. The simulations presented by the authors help in understanding and explaining the geographical outbreaks of the major epidemics taking place during the first decade of the present century and provide an estimate of the possible evolution in terms of the temporal order of the areas hit. As a matter of example, we can argue, theoretically and following what presented by such scholars, that after an outbreak in China - where infectious diseases of different kind often originated in times, although with a decreasing pace from the '60 of the past century, particularly developing as respiratory syndromes - [92], major air connections facilitated spreading in mainland and towards neighboring countries – as South Korea and Japan –, Europe and the United States, to cite some examples of major destination areas. Major air transport routes to and from China connect European destinations - count for 9.8 % of EU air traffic – with Amsterdam Schiphol, Frankfurt, London and Paris among the major airports holding the highest number of international connections (Rome Fiumicino Airport, however, presented as well a direct connection to Wuhan Tianhe International airport) [93] [94] [95].

Recent studies seem showing that the zero patient in Europe was identified in Germany, although asymptomatic, in January [12]. Also, a particularly high seasonal flu peak was registered in Germany in the early weeks of the year 2020 [96]. The outbreak conditions, however, were found in Italy, than as a consequence was hit first and in a very aggressive way.

2.1.3.3. Diffusion as a local spatial process before and after Italian Lock down

With reference to diffusion processes at regional / Italian level, we can recall some possible diffusion dynamics happened after the first two outbreaks in Vo (Veneto) and Codogno (Lombardy) around 20 February 2020. The local diffusion processes led to putting Lombardy and other provinces in Piedmont, Emilia-Romagna and Veneto in a Red Zone at the beginning of March (8 March 2020), little before the decision of putting the whole country into a unique red zone (10 March 2020), a lock down with severe limitations to individual movement and industrial production. The leak of the governmental decree draft locking down Northern Italy led to a sort of get-away of many people

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from the to-be locked provinces towards Southern destinations, with people crowding in airports and railway stations - Italian internal migrations still bring many people from Southern Italy to move to the cities in the North for working reasons. Also, many Southern Italian locations host second houses for tourism. Back-home and second-houses journeys moved people from North to South in the days before the full lockdown became fully operational. A fear arose of a spatial diffusion of the virus towards Southern regions by means of longer distance transport means (High Speed Trains; Air connections).

The containment policies evolved from mild forms concerning early affected provinces to most severe ones limiting mobility and actions. The picture we draw at the end of March 2020 can be considered as a reasonable representation of the 'natural' diffusion of the phenomenon, before the effects of the lock down policies, given the two-weeks maximum incubation time [97]; although such duration can change in time and space [98] [99] [100].

2.2 The Data

The research has been performed using different datasets mainly referred to Italy and related to the Covid-19 outbreak, as well as socio-economic and environmental data, considered useful for examining the territorial aspects of the virus outbreak in Italy.

Covid-19 data considered the number of total infected people at 31 March 2019 at province level, as reported by Italian Ministry of Health, as collected by the Civil Protection. It is to be outlined that such data as raw ones, including case were the virus not validated by the Italian Higher Institute of Health Care (ISS - *Istituto Superiore di Sanità*) that check the real cases, also after a one-to-one evaluation of the causes of death. We considered data at that day to 'close an important month' in terms of the virus outbreak, and in order to have a picture of the situation after the severe choices of national lockdown of most of the activities and individual mobility. Data after that moment were difficult to relate to diffusion processes in strict terms and more related to the regional policies taken after the national lockdown.

An important novel dataset, originally built from scratch by the research group, is the number of deaths at province level. Such data were collected from different sources, being such data not always available from the same sources. In many cases data were provided by regional administration, while in other cases the research required counting and referring data to provinces from the local health agencies, or even from other sources as newspapers providing date at local levels. Among the others, the major difficulties were found in locating at province level data for important regions in terms of the Covid-19 outbreak as Lombardy and Piedmont; also big regions as Liguria, Lazio, Campania and Sicily required an extra-effort for locating dead cases at provincial level. We succeeded in locating at provincial level 11,336 deaths over 12,428 at national level, and 102,440 infected people over 105,792 at national level.

The socio-economic and environmental data considered come from different official sources. Socio-economic and demographic data come from the ISTAT (Italian Statistical Institute - *Istituto Nazionale di Statistica*), as population, total and organized in age groups, as well as mortality, differentiated by causes, at 2019.

Environmental data and indicators come from ISPRA (Higher Institute for Environmental Protection and Research - *Istituto superiore per la protezione e la ricerca ambientale*), WHO (World Health Organization), ISS (institute higher of health) EEA (European Environmental Agency), Il Sole 24 Ore (economic and business newspaper, providing constant reports on economical facts), Legambiente (no-profit association for environmental protection), ACI (Italian Automobile Club), ilmeteo.com and windfinder.com (weather and wind data). Furthermore, for the air quality (PM2.5, PM10, NH_3, CO, CO_2, NO_x) and the weather conditions (humidity, wind, rain) were also monitored in real time through specific dashboards. In this sense, to simplify the discussion, we have elaborated the figure 9 that summarizes the data set - dynamic and static - in reference to the ecological approach used. The complete data set (open data) is shown at the end of the paper.

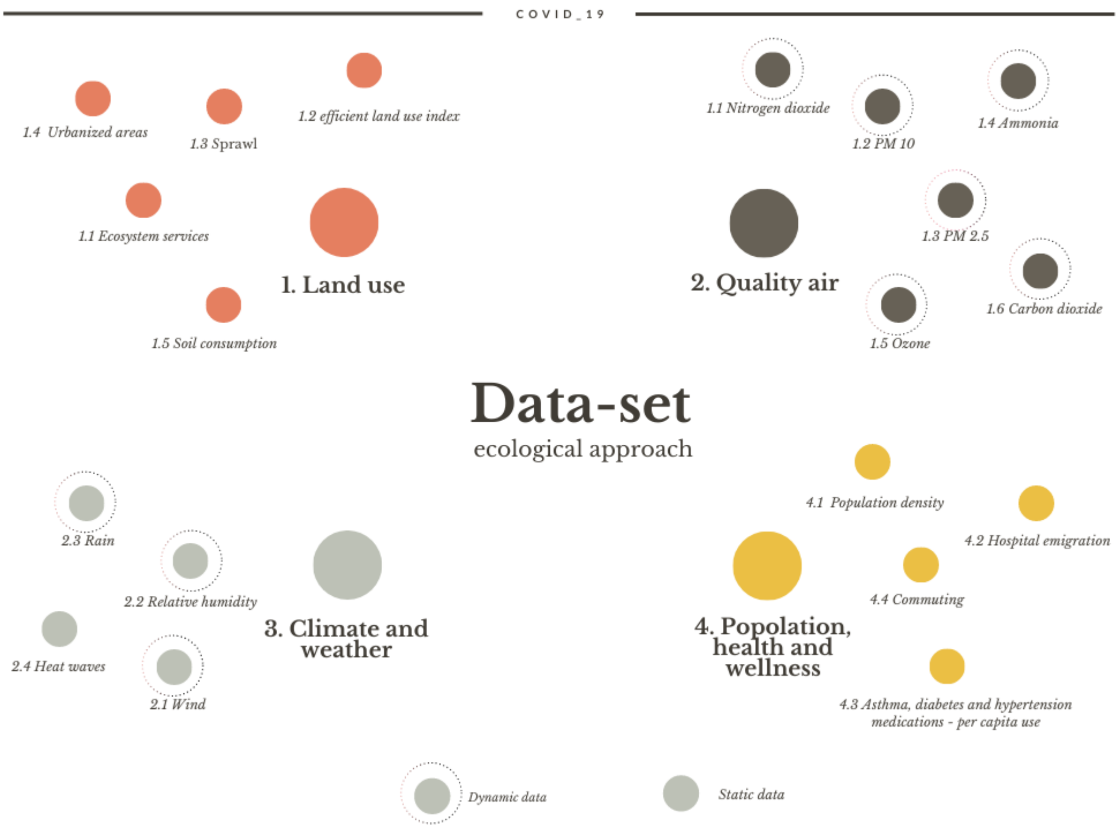

Figure 9. Data set infographic. Source: Our elaboration on multiple sources (Appendix A and B).

The spatial units we selected for this research are the intermediate level between Municipalities and Regions, as the set of spatial units once known as Provinces, now incorporating existing Provinces, in those regions where they were maintained as administrative units, Metropolitan Areas, where they did replace former Provinces as wide area administrations, and, in the regions in which Provinces were abolished from the administrative point of view, the statistical units corresponding in extension to the former provinces, for a total of 107 units. Spatial units are provided by ISTAT (Italian Statistical Institute) at 2019 year. The choice of such units, from the geographical, cartographical and spatial analytical points of view, holds several limitations, as the phenomena referred to such units tend to be diluted over irregular and non homogeneous areas, both in terms of spatial dimension, number of inhabitants and population densities, as well as incorporating several differences, not only among each other, but in terms of the spatial variation within a same area. The risk, as it is often outlined, is confusing the spatial pattern drawn by the geographical units as well as of the underlying population, instead of the phenomena per se [101] [102] [103] [104]. Such issues are however well known. It is to be outlined, however, how this choice of the spatial unit was the only one to allow a finer and disaggregate analysis at local level, not even more diluted than reasoning at Regional or Autonomous Provincial level, where the majority of data is aggregated. It has to be however pointed out that, with particular reference to mostly evident area at risk, as the Po Valley area, holds some characteristics of a space nearly homogeneous and isotropic in Christaller's terms, as, the provinces in part of Piedmont, Lombardy, Veneto and Emilia Romagna present quite comparable spatial dimensions.

Very few studies and research, at present, considered the issues related to Covid-19 at provincial level, limiting the analysis to data at regional level and, as it will be more evident in the rest of the paper, the consideration of neighboring provinces will help to understand the spatial variation of the phenomena not dependent from the regional differences.

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Also, that would have also needed reasoning at a nearly 'international' level, as the high level of autonomy granted in Italy to the 19 Regions and 2 Autonomous Provinces of Trento and Bolzano, particularly in terms of Health system and Mobility, would suggest approaching the issue as a comparison between independent states.

In this sense, the retrieval of data - open data -, their cataloging, representation and geospatial correlation has always been consistent with the ecological approach, precisely in order to evaluate the phenomena in their complexity and entirety.

2.3. Methods

2.3.1. The ecological approach

In the present paper the approach adopted is an ecological one, as the physiological traits of the virus are combined with a wide set of selected relevant environmental variables. In such sense, occurrences of the outbreak, as infected cases and deaths, were examined and referred to several variables. To do that, throughout the paper, a regional focus on the characters of the study area - the Po Valley in the context of Italy from the different points of view - is carried on, in terms of the physical and human-economic geographical characters, describing them and observing them from a qualitative and quantitative point of view. The Po Valley area - Great Milan metropolis in particular - is performed, recalling the similarities with Hubei - Wuhan areas - in order to analyze the potential analogies with the conditions of Covid-19 outbreaks. To do that, we concentrate on particular elements related to aspects that, in an integrated manner, can be considered important in understanding the human-environment relations between human activities, geographic and climatic conditions and virus outbreaks. Focus on air and climate characteristics and on soil consumption, as the common features concerning several human-related behaviors affecting the environmental balance, are also carried on. In fact, as soil consumption increases, the storage capacity for air purification decreases and more generally a deterioration of the physical, chemical, biological and economic characteristics connected to it [105]. In other words, land take interferes with collective well-being [106]. In this sense, ecosystem services play a key role for collective well-being: ecological, social and productive [107] [108]. Our research effort is part of this interdisciplinary ecological approach to investigate the spread of Covid-19 in Italy, based on a theoretical analysis and on a quantitative analysis on a large dataset of environmental variables.

2.3.2. Calculation of Case Fatality Rate

The absolute frequencies of deaths by province, obtained through the reconstruction of data from distinct information sources, have been compared with the number of positive Covid-19 cases published by the Istituto Superiore della Sanità [6], according to the formula:

$$Covid19\ case\ fatality\ rate\ by\ province\ = \frac{number\ of\ cases\ of\ death\ observed}{number\ of\ positive\ subjects\ per\ national\ province}, \quad (1)$$

2.3.3. Calculation of the Standardized Mortality Ratio (SMR)

Standardized Mortality Ratio is a standardization method used to make comparisons of death rates between different regions, considering that a given region can have a population older than another, and considering that younger people are less likely to die than older people. To do that, there is the need to investigate the pattern of deaths and the dependency to the age composition. For each areal unit, based on the distribution of population by age group, and the age-specific rates of deaths in some wider population, the expectation of number of deaths is calculated. The ratio of observed over expected deaths is calculated. A value of 1 indicates that the area considered is behaving 'as expected' in terms of mortality, in line with that of a wider reference area. Values higher than 1 show a mortality that is higher than that expected, even in terms of population structure, while values lower than 1 suggest mortality is reduced and lower than expected [109].

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Cause specific mortality from Covid-19 has been standardized for each Italian province and for age groups - 10 groups; first group 0-9 years; last group 90-∞ -, with reference to the national population figures in the year 2019 [110]. The indirect standardization process initially provided for the calculation of national specific mortality by age group, obtained by dividing the number of Covid-19 deaths confirmed by the Italian Higher Institute of Health Care (ISS - Istituto Superiore della Sanità) [6] with the 10 defined age groups. Thus, the number of deaths expected in the Italian provinces for the age groups previously identified and based on the 2019 provincial populations [110], was calculated according to the formula:

$$e = \sum_{i=1}^{K} n_i R_i \quad (3)$$

where n_i is the specific age group population in each observed area (province); R_i is the national mortality rate for the specific age group.

The Standardized Mortality Ratio (SMR) was obtained by comparing the number of events observed in each province with the respective number of expected events:

$$SMR = 100 \frac{d}{e} \quad (2)$$

where d is the number of observed deaths; e the number of expected deaths.

Finally, the 95% confidence intervals (95% CI) were calculated as proposed by Vandenbroucke [111].

2.3.4. Spatial Autocorrelation

When dealing with data referred to spatial units, the characters involved are locational information and the properties or 'attribute' data. The pattern drawn by geographical features and the data referred to them can be mutually influenced, resulting in spatial autocorrelation. In geographical analytical terms, it is the capability of analyzing at the same time locational and attribute information [112]. The study of spatial autocorrelation can be very effective in analyzing the spatial distribution of objects, examining simultaneously the influence of neighbor objects, in a concept anticipated by Waldo Tobler [113] in the first law of geography, stating that "All things are related, but nearby things are more related than distant things". In spite of this approach is very simple and intuitive [114] and very important in a huge variety application domain, for more than twenty years it has not been applied [115].

Adopting Goodchild [112] approach, Lee and Wong [116] defined spatial autocorrelation as follows:

$$SAC = \frac{\sum_{i=1}^{N}\sum_{J=1}^{N} c_{ij} w_{ij}}{\sum_{i=1}^{N}\sum_{J=1}^{N} w_{ij}}, \quad (4)$$

Where:

1. i and j are two objects;
2. N is the number of objects;
3. c_{ij} is a degree of similarity of attributes i and j;
4. w_{ij} is a degree of similarity of location i and j;

This general formula gave origin to two indexes widely used in spatial analysis, as Geary C Ration [117] and Moran Index I [118].

Defining x_i as the value of object i attribute; if $c_{ij}=(x_i-x_j)^2$, Geary C Ratio can be defined as follows:

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$$C = \frac{(N-1)\,(\sum_i \sum_j W_{ij}\,(x_i - x_j)^2}{2\,(\sum_i \sum_j W_{ij}) \sum_i (x_i - \bar{x})^2}, \tag{5}$$

If $C_{ij} = (x_i - \bar{x})(x_j - \bar{x})$, Moran Index I can be defined as follows:

$$I = \frac{N\,\sum_i \sum_j W_{ij}\,(x_i - \bar{x})(x_j - \bar{x})}{(\sum_i \sum_j W_{ij}) \sum_i (x_i - \bar{x})^2}, \tag{6}$$

As recalled in Murgante and Borruso [119], these indices are quite similar, with the main difference in the cross-product term in the numerator, calculated using the deviations from the mean in Moran, while in Geary it is directly computed.

The indices are useful for highlighting the presence - or absence - of spatial autocorrelation at global level in the overall distribution, while the local presence of autocorrelation can be highlighted by the so called LISA, or Local Indicators of Spatial Association. Anselin [120] [121] considered LISA as a local Moran index. The sum of all local indices is proportional to the value of Moran one:

$$\sum_i I_i = \gamma\, I, \tag{7}$$

The index is calculated as follows:

$$I_i = \frac{(X_i - \bar{X})}{S_X^2} \sum_{j=1}^{N} (W_{ij}\,(x_j - \bar{x})), \tag{8}$$

It allows, for each location, to assess the similarity of each observation with its surrounding elements.

Five scenarios emerge:

• locations with high values of the phenomenon and high level of similarity with its surroundings (high high H-H), defined as hot spots;

• locations with low values of the phenomenon and low level of similarity with its surroundings (low low L-L), defined as cold spots;

• locations with high values of the phenomenon and low level of similarity with its surroundings (high low H-L), defined as potentially spatial outliers;

• locations with low values of the phenomenon and high level of similarity with its surroundings (low high L-H), defined as potentially spatial outliers;

• locations completely lacking of significant autocorrelations.

The interesting property of LISA is providing an effective measure of the degree of relative spatial association between each territorial unit and its surrounding elements, allowing highlighting type of spatial concentration and clustering.

An important element to be considered in the above mentioned equations is the parameter weight, w_{ij}, related to the neighborhood property. Generally, w_{ij} [122] values indicates the presence - or absence - of neighboring spatial units to a given one. A spatial weight matrix is realized, with w_{ij} assuming values of 0 in case i and j are not neighbors, or 1 when i and j are neighbors. Neighborhood is computed in terms of contiguity, as, in case of areal units, sharing a common border of non-zero length [104]. Adopting chess game metaphor [104], contiguity can be considered as allowed by paths of rook, bishop and queen.

3. Results

Through the evaluation of the elaborations from the data collected for this research, according to an interdisciplinary ecological approach referring to different scales from global to provincial, we have been able to obtain some important results, which we believe will also be developed in a subsequent research.

3.1. Mortality rates, SMRs, Population Density, Commuting

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Observing the elaborations from data originally collected for this research, as the death cases at provincial level, what actually required a careful search for correctly attributing the regional values to such an intermediate level, integrating different data sources, generally not communicated officially, some first important results can be observed, providing an improved picture of what, instead, portrayed at regional levels in term of deaths, and about the diffusion in terms of the positive cases. The letal cases are observed in relative terms - to population - and as standardized data. Starting from the data collected at provincial level and related to death cases, we could produce a map of the number of Covid-19 related deaths to the population of the area, in order to rely on an indicator more comparable than the raw value. Deaths were related to 50,000 inhabitants (Fig. 10).

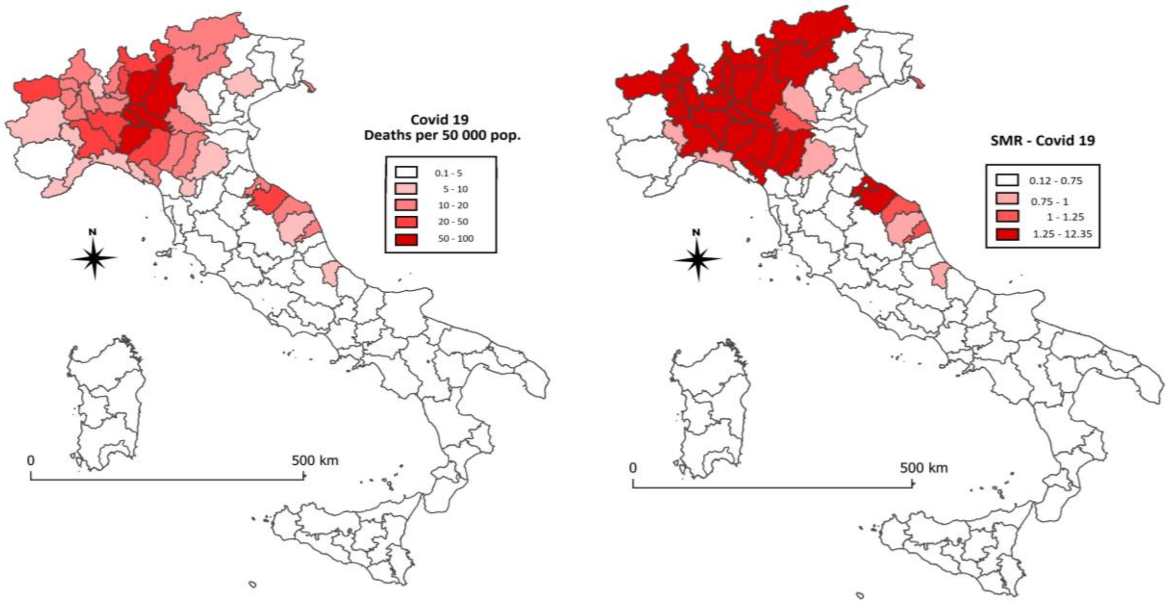

Figure 10. Covid-19 related Deaths. (a). Deaths per 50,000 population; (b). Standardized Mortality Ratios. Source: our elaboration from data originally collected; ISTAT 2019 (population)

The 5-class classification shows a majority of provinces, mainly distributed in Central and Southern Italy - major islands included - present a number of deaths per 50,000 inhabitants below 5, confirming a relatively low diffusion of the virus in such part of the country. The highest values can be found in the five provinces Northeast, East and Southeast of Milan - Bergamo, Brescia, Cremona and Lodi in Lombardy region; Piacenza in Emilia Romagna (Fig. 11).

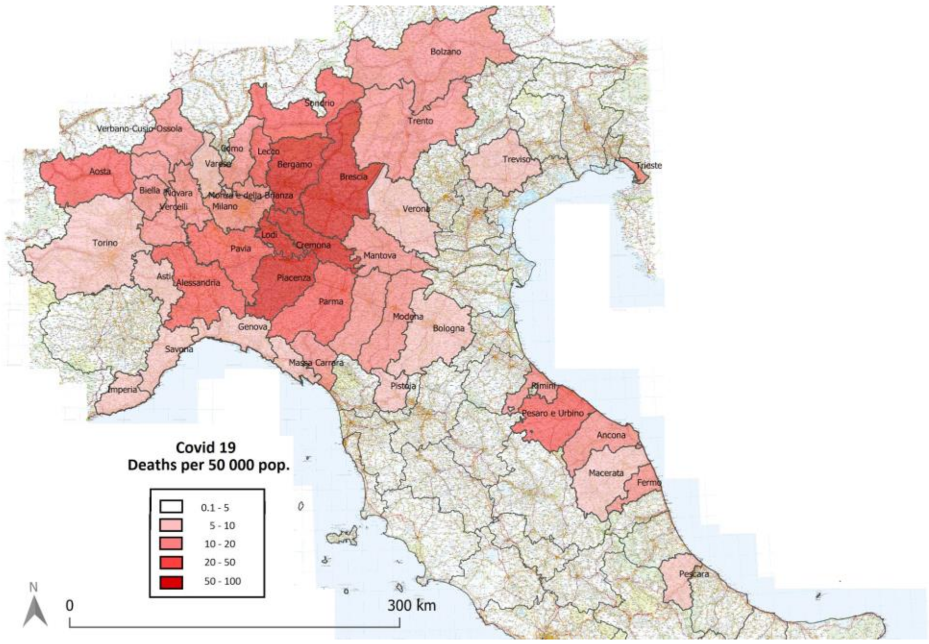

Figure 11. Deaths per 50,000 population. Focus on the Po Valley Area. Source: our elaboration from data originally collected; ISTAT 2019 (population)

The death 'density' seems to be decreasing out of such a core area. Central and Southern Italian provinces seem having very low values, a part from the peaks thath can be found in Southern Emilia Romagna - Province of Rimini - and Marche region - Province of Pesaro in particular.

The Standardized Mortality Ratio (SMR) represents a further relevant analysis, fundamental at this stage of the research on the Covid-19 Italian outbreak in order to cope with age as confounder. As introduced above, it compares the Covid-19 mortality with that expected, based on the 2019 data. The thematic map produced show a neat separation of the unity - below unity values, representing the Italy provinces where, at 31 March 2019, mortality is in line with expected forecasts or even lower. In other provinces, namely the Western Po Valley provinces, including mountain ones, and on the Adriatic Coast of Emilia Romagna and Marche Regions, the standardized mortality is much higher than expected. It is interesting to notice that also major urban areas - Turin, Verona and Bologna present values around lower figures of unity, showing a mortality apparently less affected by the Covid-19 outbreak. LISA maps on the indicators related to such phenomena - Cov_57, Cov_58, Cov_65, Cov_66 - confirm these first evaluations. (Fig. 12 and 13)

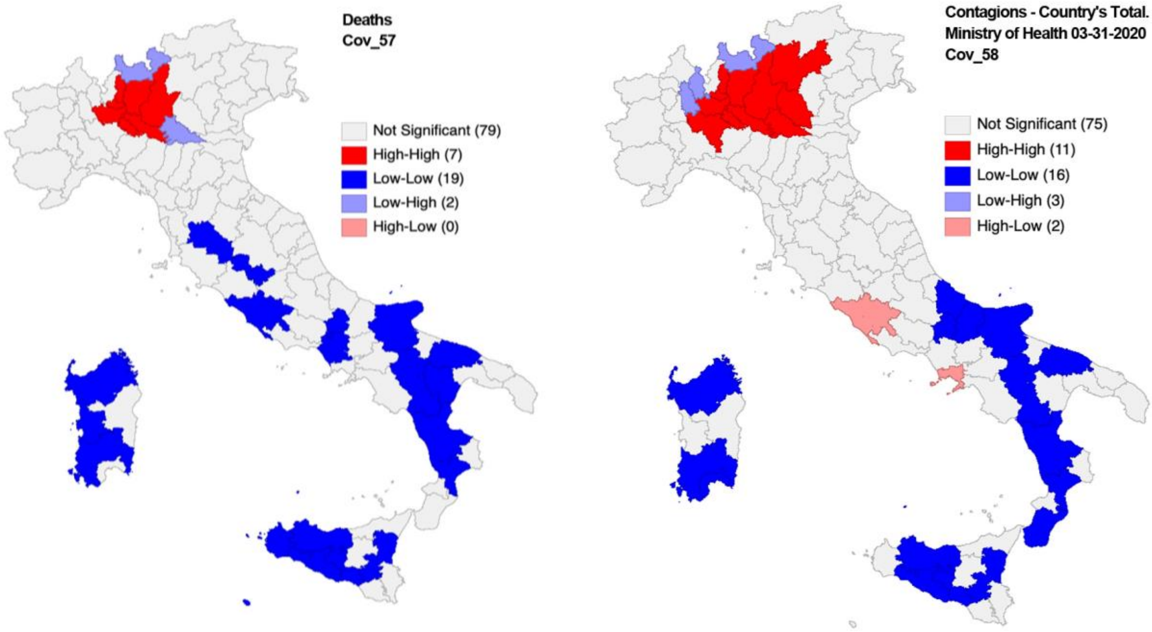

Figure 12. Lisa Maps: Cov_57 Deaths; Cov_58 Contagious. Source: Our elaborations (GeoDa) from data as in Appendix A and B

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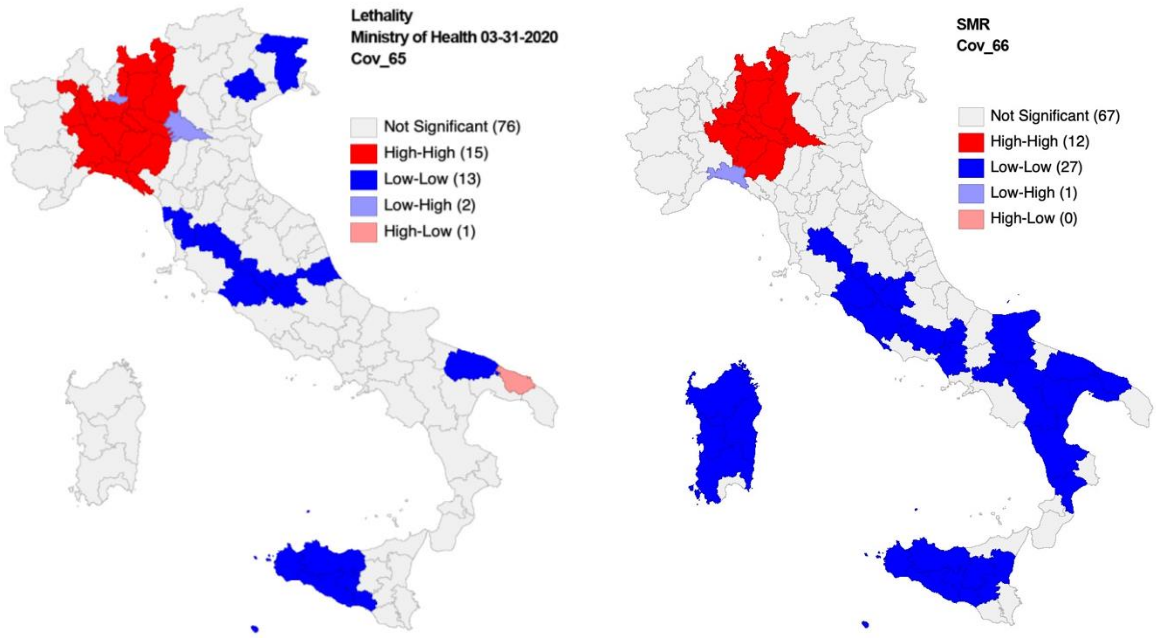

Figure 13. Lisa Maps: Cov_65 Lethality; Cov_66 SMR. Source: Our elaborations (GeoDa) from data as in Appendix A and B

These data were also compared to some other indicators typical of the 'human geography' of the area, as population density and commuting. The first element - population density - as already presented in the study area section at, where density was portrayed at the finer resolution of the municipality level - is particularly characterizing the Po Valley area, namely in two distinct areas, the foothills of the Alps in the North, and the Appeninian ones in the South, although this latter with much lower values. The Greater Milan area, including Bergamo, one of the most provinces affected by the Outbreak, appear as the most uniform and denser one (Fig. 14).

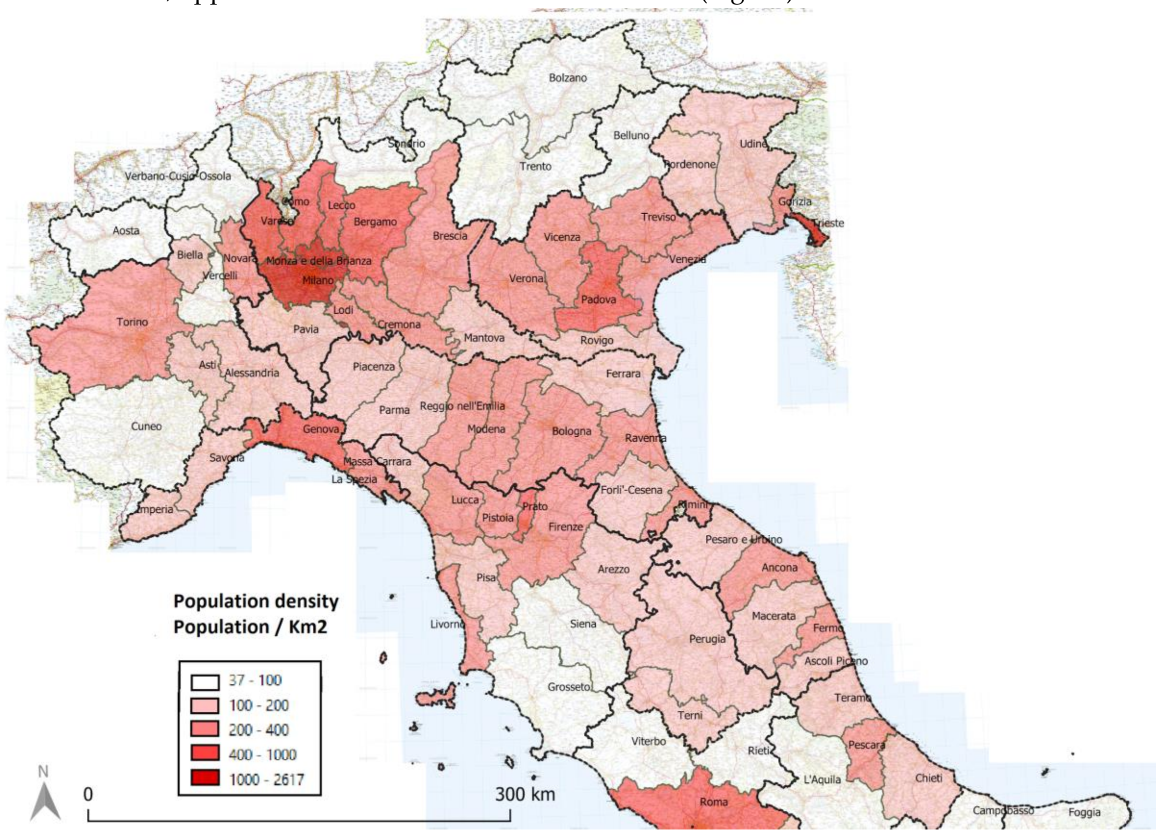

Figure 14. Population density. Population / Km^2. Focus on the Po Valley Area. Source: our elaboration from data originally collected; ISTAT 2019 (population).

That is also confirmed by the LISA analysis (Fig. 16 Lisa cov_64 and 83).

A second element is related to mobility. Commuting - although data were taken from the 2011 census as available for the whole country - are considered here. Different indicators were considered. Two Commuting Indexes were used. The first, standard one, considers the difference between incoming and outgoing flows over the population of the area. A second index we used here considers the sum of incoming and outgoing flows over the internal flows of the area. The first index tends to emphasize those areas that act as either as attractors - values higher than 1, meaning that incoming flows are higher than the outgoing ones - or tributary areas - values lower than 1, meaning that outgoing flows are higher than the incoming ones. The magnitude of the index indicates the 'weight' of the area as capacity of attracting people from neighboring areas, emphasizing metropolitan areas and central cities in a given system. For our purposes, however, it was considered more interesting to consider the latter index to observe the overall degree of mobility of the area, proposing such a comparison between extra-provincial flows and internal ones (Fig. 15). The Commuting Index (1) shows, in the darkest color, with values higher than ones, the metropolitan centers, those attracting the higher flows of commuting over population. Major cities and metropolises are highlighted. The Commuting Index (2) shows, the overall mobility - inbound and outbound - particularly in the highest classes. It can therefore depicts both areas of wide mobility and metropolitan roles, as well as a high level of 'openness' in terms of flows.

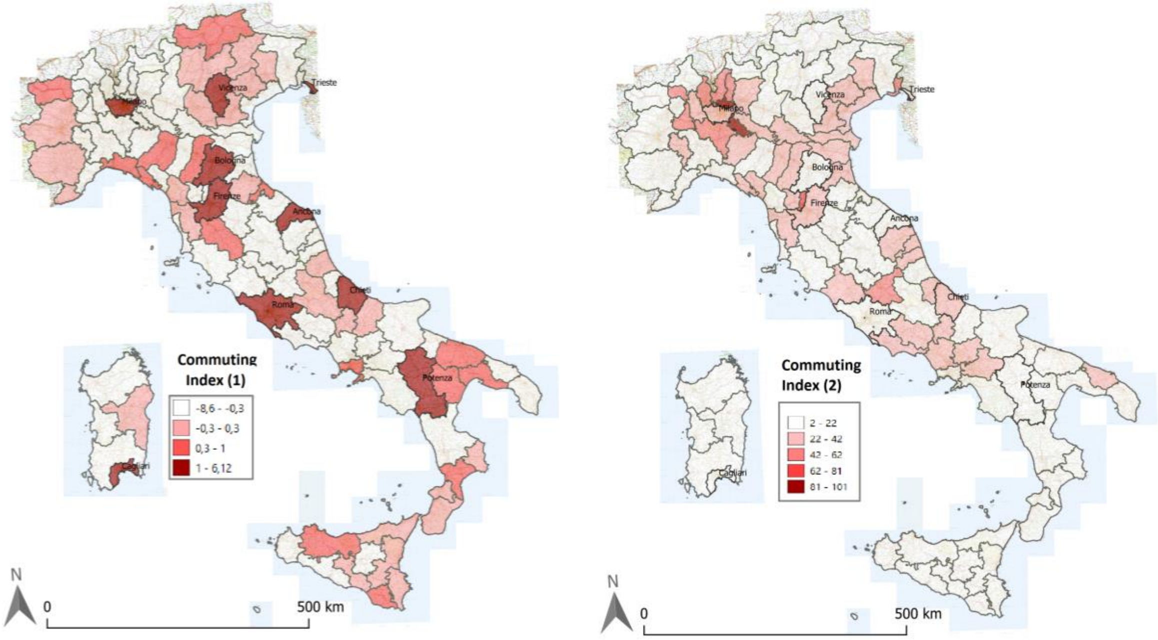

Figure 15. Commuting indexes (a) Commuting index (inflows-outflows / population); (b) Commuting index (inflows outflows/internal flows)

This analysis was confirmed by means of LISA - Cov_83, that displays a self-containment of the Greater Milan area in the extension as it was introduced in the study area paragraph.

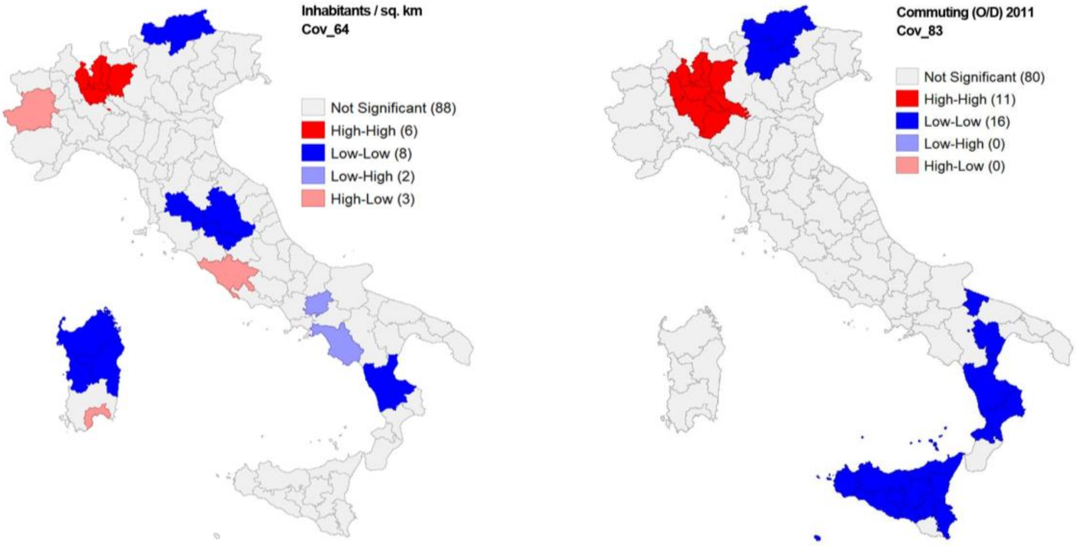

Figure 16. Lisa Maps: Cov_64 Inhabitants; Cov_83 Commuting. Source: Our elaborations (GeoDa) from data as in Appendix A and B

3.2. Local climate change and air quality

The first comment must be made with reference to the local climate changes affecting the megalopolis of the Po Valley (Fig 17) and the significant change of the relative humidity and air quality [123].

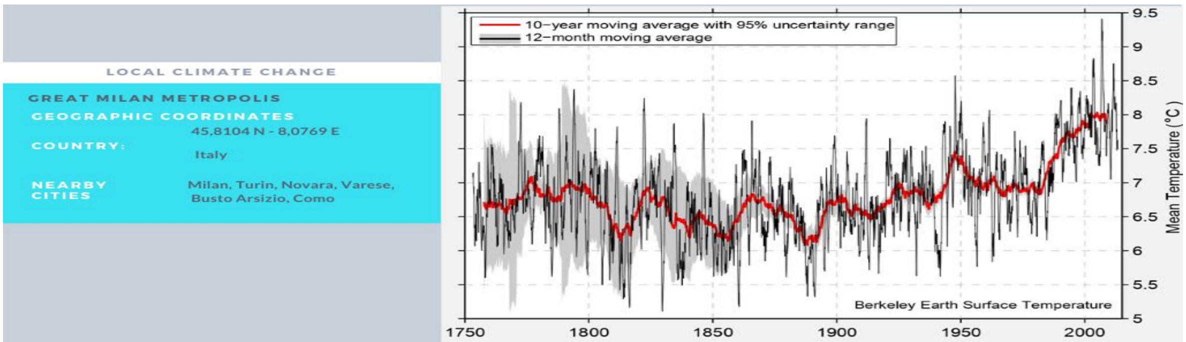

Figure 17. Local Climate Change - Great Milan Metropolis. Source: Authors elaboration from http://berkeleyearth.lbl.gov/city-list/

These are apparently unconnected phenomena, which in fact, in addition to being deeply dependent on each other, act not as a simple sum on environmental ecosystems and on the community, but in the form of combinations which are in turn correlated with urban geography - land use: efficient land use, sprawl and ecosystem services.

In particular, we have found different regulations in relation to different states, so air quality is not an equal concept for everyone. In this case, to better represent the PM 2.5 situation, we used WHO guidelines - 2005: daily limit 25 μg/m^3; year limit 10 μg/m^3; Italian legislative decree 13 August 2010, no. 255: year limit 25 μg/m^3 lowered to 20 μg/m^3 from 1 January 2020 - we elaborated the following figure 18.

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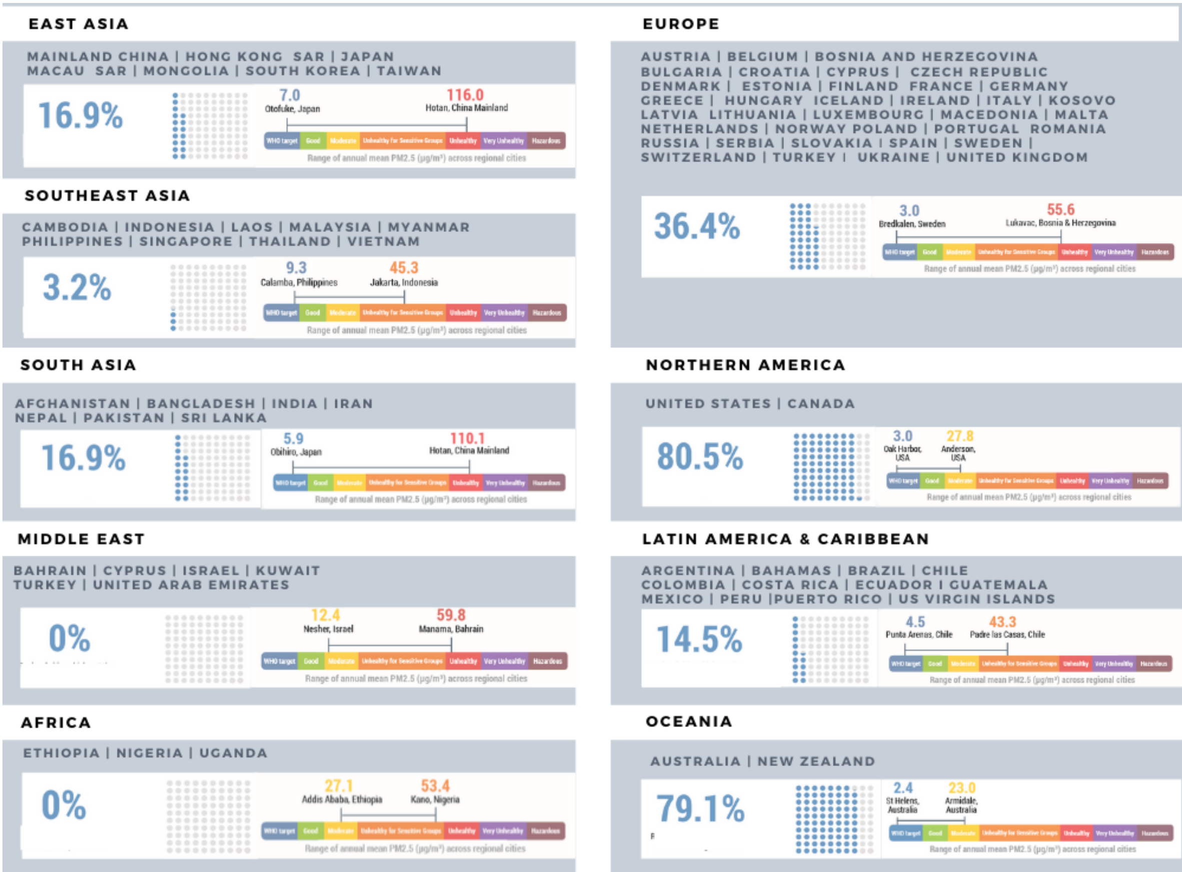

Figure 18. WHO Regions which met the PM2.5 target in 2019. Source: Authors elaboration from https://www.iqair.com/

The figure 18 highlights how the EU presents about 40% of the cities complying with the WHO 2005 guidelines, the critical learning concentration for a sensitive part of the population - General public and sensitive individuals in particular are at risk to experience irritation and respiratory problems [124].

Among the urban areas that do not respect the WHO target there is also the Megalopolis of the Po Valley - Italian economic core, high population density and strong commuting (interregional on the EAST side).

Furthermore, according to EEA (2018) [125] the sectors that continue to contribute to the formation of PM2.5 are the commercial, public institutions and household. Similarly, this also happens for PM10, which was found in the Po Valley and remained high throughout the Italian lockdown period [126] and mainly produced by heating. This failure to reduce PM10 is in fact attributable to the limited progress recorded in Italy on savings on final domestic energy consumption. In fact, since the beginning of the century, our country has shown an improvement performance of 11.6%, well below the European average value, above 30%. According to the European classification for energy efficiency of buildings (Energy Performance Class, EPC) over 70% of Italian homes fall into a class higher than D [127]. Furthermore, again in Italy due to the non-renewal of diesel cars with electric and hybrid cars (16% registration in 2019), diesel cars have been replaced with petrol ones. So after several years of improvement, CO_2 emissions since 2017 have increased every year [128]. In this ecological approach aimed at evaluating why Northern Italy was marked by Covid-19, the data set - selected from different sources and open data) used for the development of the Lisa Maps played an important role, which support and confirm our interdisciplinary assessment. In particular, the LISA maps on indicators relating to these phenomena: Cov_14, Cov_15, Cov_19 and Cov_72 - confirm these first evaluations of the air pollution in Po Valley megalopolis (Fig. 19 and 20).

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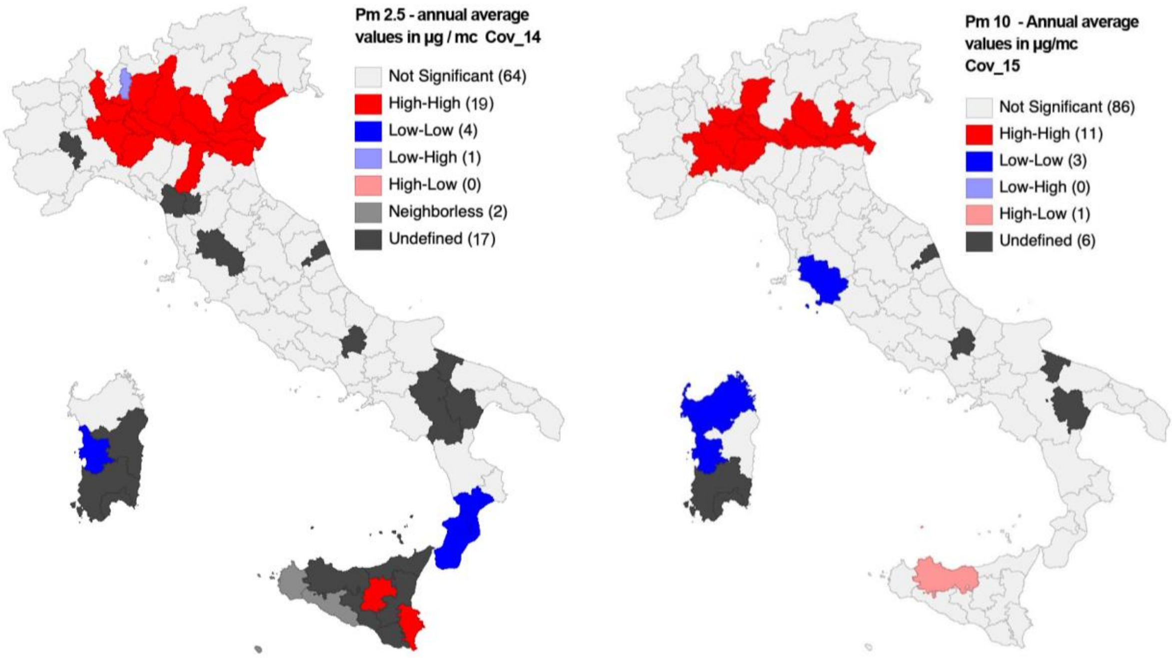

Figure 19. Lisa Maps: Cov_14 PM2.5; Cov_15 PM10. Source: Our elaborations (GeoDa) from data as in Appendix A and B

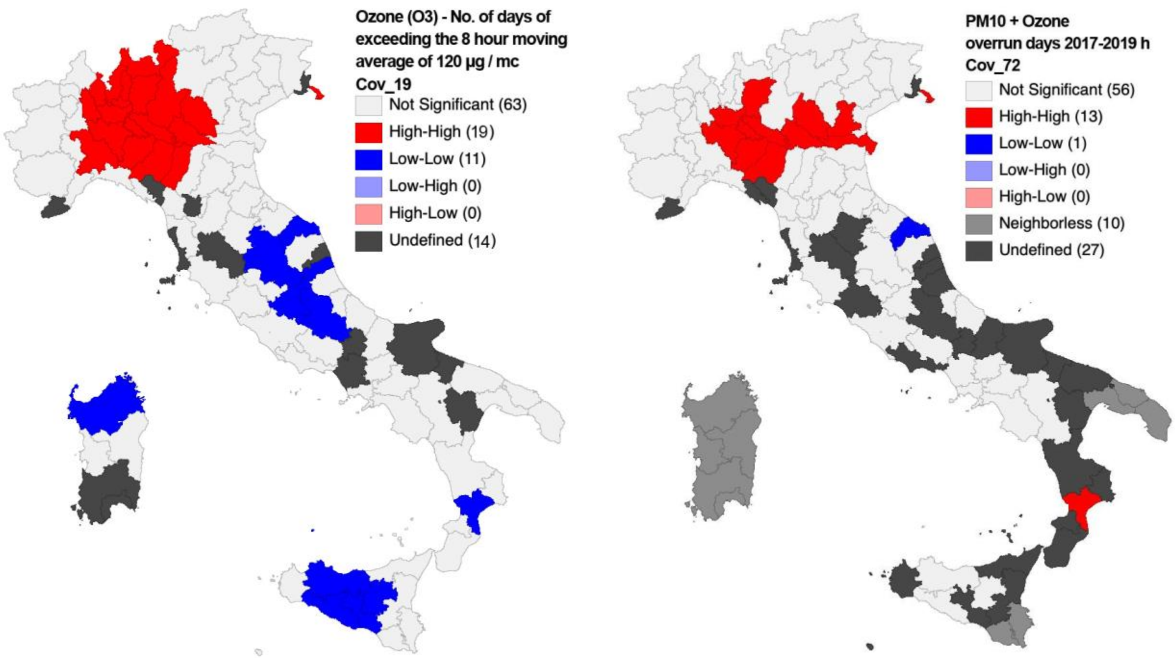

Figure 20. Lisa Maps: Cov_19 Ozone; Cov_72 PM 10 and Ozone. Source: Our elaborations (GeoDa) from data as in Appendix A and B

In this complex picture of air pollutants into the air, from the diversity of the assessment of international targets and the relative multiple production sectors, in Italy and in particular in the Po valley, the handicap is added: of physical geography - river valley - and climatic conditions - climatic well-being index: sunshine, perceived temperature, heat waves, extreme events, breeze, relative humidity, gusts of wind, rain, fog - which significantly condition the air quality [129].

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In these sense, the LISA maps on indicators relating to these phenomena: Cov_37, Cov_39, Cov_41, Cov_55 confirm these the evaluations of climate condition (Fig. 21 and 22).

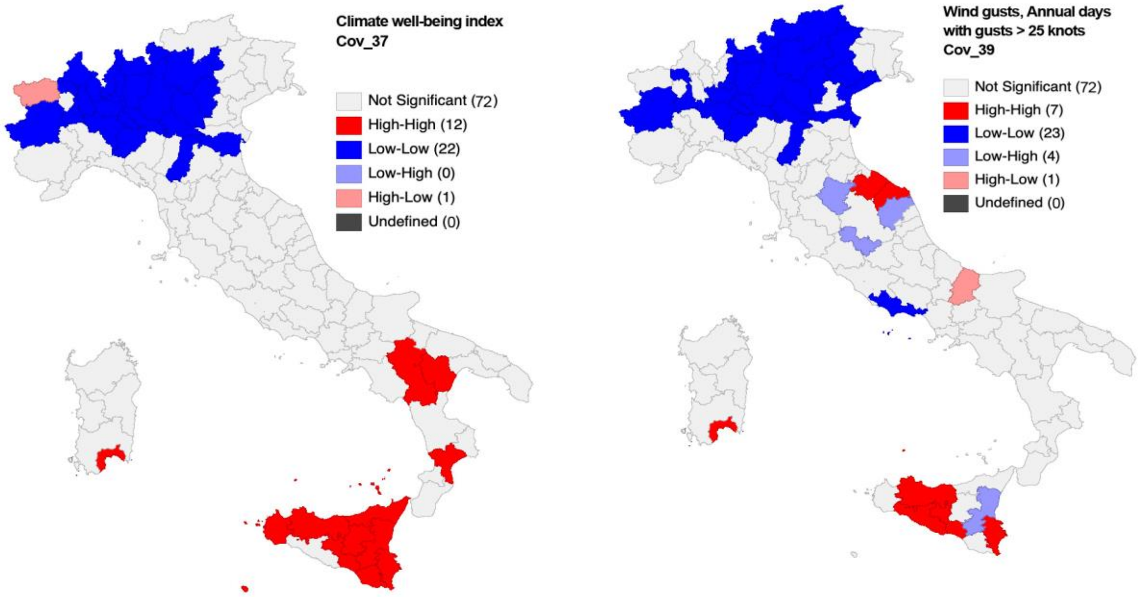

Figure 21. Lisa Maps: Cov_37 Climate well-being index; Cov_39 Wind gusts. Source: Our elaborations (GeoDa) from data as in Appendix A and B

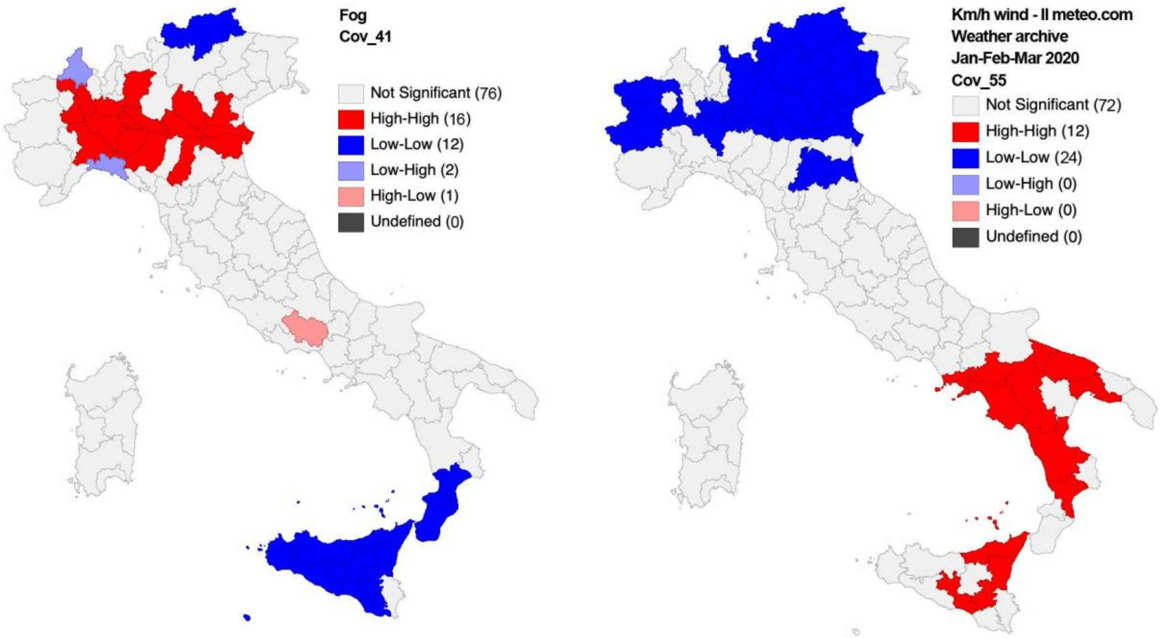

Figure 22. Lisa Maps: Cov_41: Fog; Cov_55: wind- Jan/Feb/Mar 2020. Source: Our elaborations (GeoDa) from data as in Appendix A and B

Recalling that climatic variations affect air quality and air pollution induces climatic variations we can argue that the Lisa Maps have constituted a valid support for the evaluation of autocorrelation, which will be the subject of further research developments.

3.3. Land take and COVID-19

As previously explained, the physical conformation of the northern part of Italian peninsula is influenced by the Alpine Chain. It represents a sort of barrier to wind which influences air circulation and distribution. This hypothesis has been confirmed by LISA analysis Cov_39 (Fig. 21), which highlights a strong spatial autocorrelation of low level of data concerning annual days with gusts of wind greater than 25 knots.

Considering also that in this area the great part of productive activities are concentrated, it should be important to have a lot of not urbanized areas capable of allowing CO_2 storage. Cov_82 (Fig. 24) shows high values of spatial autocorrelation of CO_2 related to not urbanized areas. In particular, the areas with the greatest number of positive cases and deaths do not have enough space with natural functions able to store the produced CO_2.

Considering this structural features of the territory, unsealed soils can play a fundamental role in CO_2 storage and, at the same time, green areas can be very useful in improving air quality, reducing PM2,5, PM10 and O_3. The lack of forests and vegetated areas able to raise air quality, determining a decrease of PM2,5 PM10 and O_3, is highlighted by figures 19 and 20 where the highest values of spatial autocorrelation occur in Covid-19 red zones.

The Italian Institute for Environmental Protection and Research (ISPRA) produces an annual report on Land Take, Territorial Dynamics and Ecosystem Services, which highlights all the critical issues [130]: unfortunately, according to this report, the northern part of Italy is the area where the phenomenon of sprawl is more concentrated.

This trend is also confirmed by spatial autocorrelation analysis. Figure 23 and 24 (Cov_3, Cov_52, Cov_49 and Cov_82) consider respectively land take between 2014-2018 and up to 2000, sealed soils at 2016 and CO_2/non urbanized areas. Also, in this case the highest values of LISA index are concentrated in Lombardy region.

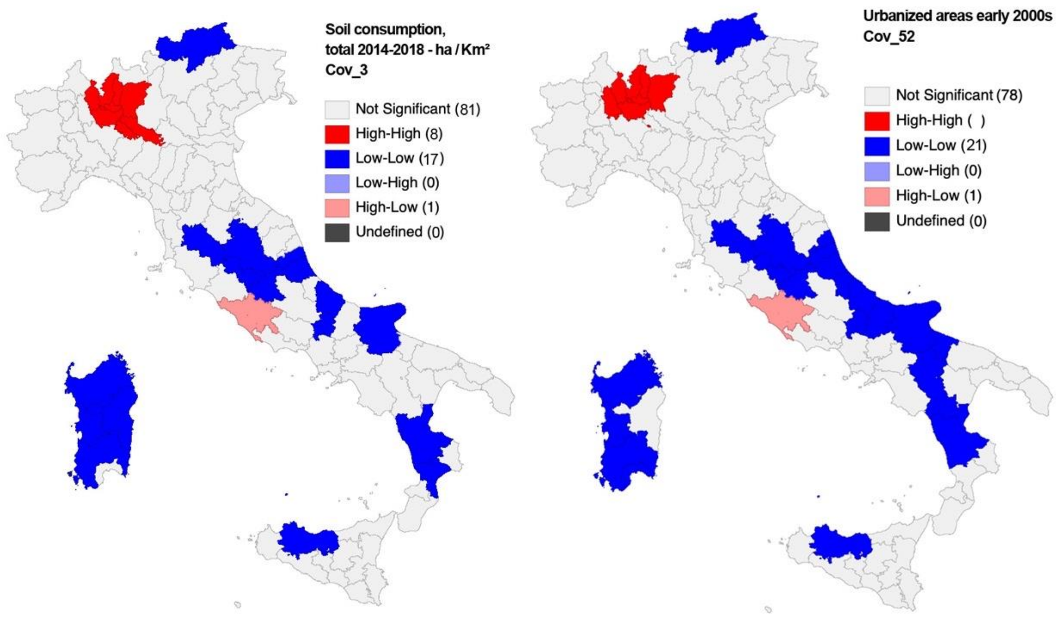

Figure 23. Lisa Maps: Cov_3: land take between 2014-2018; Cov_52: land take up to 2000. Source: Our elaborations (GeoDa) from data as in Appendix A and B

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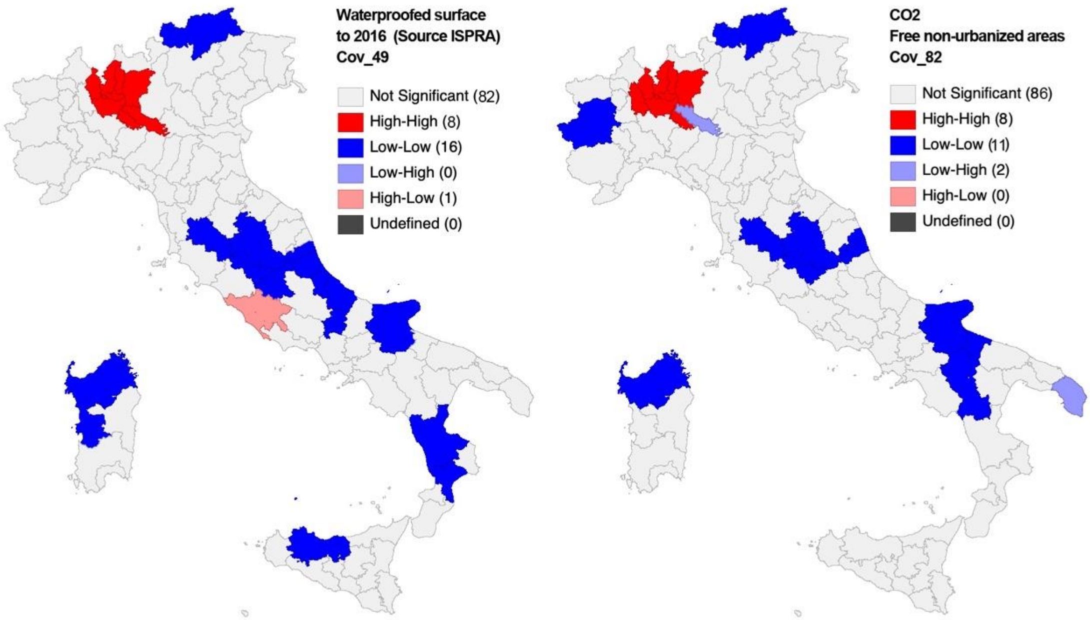

Figure 24. Lisa Maps: Cov_49: sealed soils; Cov_82: CO2/non urbanized areas. Source: Our elaborations (GeoDa) from data as in Appendix A and B

Martellozzo et al. [131] analysed at national level how an approach based on Laissez-faire generated an uncontrolled growth in great part of the country. In particular, this trend is more concentrated in the northern part of the country.

In this study, two simulations of Land use change in 2030 have been developed, the first one adopts a more sustainable approach and the second considers a development business as usual. Despite big differences in urban sprawl between the two scenarios, in the northern part of Italy land take reaches important values, also analysing the sustainable scenario. This trend has been described in Lombardy region with a detailed analysis on Milan and Brescia by Pileri [132].

This phenomenon is mainly due to the implementation of investments in total absence of planning or with very old tools. Even in the case of recent planning, the new tools have been with old laws generating a paradoxical gap between the plan contents and territorial reality, for this reason some authors adopt the term Vintage Urban Planning [133] or Ghost Planning [134]. Great part of interventions are carried without an overall strategic framework able to relate investments to territorial features [135]. This is possible because in a lot of cases the municipalities have got old plans, with demographic projections calculated in periods with great population growth, producing an impressive availability of development areas with a high probability to never completely use them to this aim. In the more competitive area of the country - e.g Northern Italy -, these lands are owned by big companies that decide to transform them, not just for selling, but also for the advantage that could be achieved inflating their accounting budget, assigning real estate assessments higher than market values [136] [137]. The continuous urbanization of northern Italy is also due to the strong demand deriving from migratory flows from Southern Italy and from abroad [138].

4. Discussion

4.1. Diffusion processes, local and global effects

In this framework we hypothesized some characters of the diffusion process occurred in Italy in the early stages of the virus outbreak among the different areas, provided that a quite limited set of data is to-date available and the process appears as still ongoing, a conclusion cannot therefore be drawn yet.

A part from the debate concerning the existing relation between the two virus hotbeds, Codogno and Vo, we could argue that, being them minor centers in their areas, we faced a hierarchical, bottom up diffusion process towards medium and major centers in Lombardy, Piedmont, Veneto and Emilia Romagna regions. Codogno in particular is located in the center of a triangle of three medium-size cities, as Piacenza, Cremona and Lodi - at top of particulate emissions in Italy for several years, as in Table 1 - very well connected to the Milan area and the industrial region on its Eastern outskirts. The connected motorway and state road system is the backbone of commuting in an area characterized by a high level of accessibility - although often saturated in terms of heavy trucks and car congestion. The A4 Turin - Trieste Motorway connects the main cities and industrial areas North of the Po river in the Metropolitan city - in functional terms - of Milan. This appears to be the area mostly affected by Covid19 outbreak - the provinces of Bergamo and Brescia in particular. A second important Po Valley leg can be identified in the Southern part of the Po Valley, towards the Apennine mountain chain foothills, following a Northwest - Southeast direction, in line with the A1 - A14 Motorways axis - crossing in Bologna - and the 'Via Emilia', the State road following the homonymous Ancient Roman road, from Milan - in Lombardy to Ancona in Marche regions. Herewith we can find some of the main diffusion locations in the Southern part of the Po Valley - cities on the Via Emilia Milan, Codogno, Piacenza, Parma, Reggio Emilia, Modena, Bologna Forlì, Cesena and Rimini. From the road transport network point of view, an important segment is characterized by the A21 Motorway connecting Brescia to Piacenza and the A1 Motorway, often used as a direct connection from the Southern part of the Western Po Valley to the industrial areas of Bergamo and Brescia Provinces, as well as a by-pass for accessing the city of Milan from South, avoiding congestion of the A1 accessing the orbital route around the city (Fig. 25).

The bottom up, hierarchical diffusion process possibly reached such medium and bigger centers, spreading then, as waterfall, top down, towards minor centers, and activating again local contagious processes. Such higher order centers can be considered as those cities hosting specialized services and facilities, as hospitals, health care structures and retirement houses.

Hierarchical, top down diffusion however presumably occurred mainly from medium-density and size cities: Bergamo, Brescia, Cremona, Parma Piacenza, Rimini, Pesaro, just to cite among the most involved ones were severely hit, but proportionally less than major centers as the same Milan, Turin and Bologna. These latter, major cities could be mainly involved, in their numbers, by the presence of hospitals and retirement homes as hotbeds for further infection, rather than as dense environment favoring stronger diffusion processes.

We cannot make particular considerations, at this stage of data availability and knowledge, regarding the pre and post lock down periods, about the spreading of Covid-19 by hierarchical diffusion processes related to medium and long connections, as air and rail transport - including high speed trains, particularly in the from North - South corridors, and it will deserve attention in further research.

The above mentioned considerations about Covid-19 local spatial diffusion, as well as the issues related to air quality and land take, can be observed also, other than by the analysis of the results from the different methods adopted, by a synthetic table (Table 1). Here we ranked the Italian provinces where the SMR - Standardized Mortality Ratio at 31 March - is higher than 1, so where an increase of mortality than expected is presented. It is a set of 29 provinces, where, as a matter of example, to remain in Po Valley area - a city like Milan, with SMR of 1.276, shows an increase in the mortality of 27.6%, while Bergamo, with a value of 12.356, present an increase 12 times more than expected. We can notice that the most affected areas are localized in the Po Valley and particularly they are characterized by a heavy presence of days exceeding limits' emissions for air particulate, as well as soil consumption. There could be noticed also a similarity in density classes, being mainly included between 300 and 400 people per square kilometers. As other research pointed out [25], they host their provincial capital of a dimension spanning from 100,000 to 200,000 (Fig. 25). Furthermore, a similar level of high, interprovincial mobility is resembled, being most of the cities tributary of other major metropolitan areas, or traffic collectors because of the presence of major industrial activities - i.e., Bergamo and Brescia - a negative Commuting Index (1) suggests generally major outgoing flows towards other centers; high Commuting Index (2) suggests a high level of overall external mobility and therefore openness to other provinces and areas. Such elements appear as interesting in helping understanding both the potential local diffusion of the Covid-19, as well as understanding the patterns and consequences on the air quality and land take.

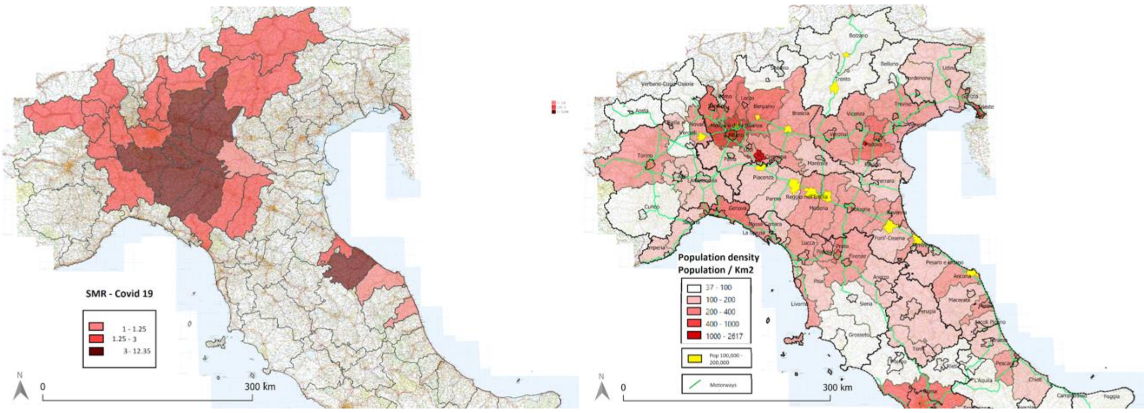

Figure 25. (a) Population density, motorways and average size provincial capital municipalities (100,000 - 200,000 population); (b) SMR . Source: our elaboration from data originally collected; ISTAT 2019 (Population); Ministry of Transport and Infrastructure (Motorways)

Table 1. Selected Provinces ranked by SMR (>1)

Province	Population (2019	Population / km²	Commuting Index (1)	Commuting Index (2)	SMR	PM10 + O_3*
Bergamo	1114590	404.59	-1.71	22.27	12.356	349
Lodi	230198	294.01	-8.6	94.66	12.262	448
Piacenza	287152	111.05	-0.62	23.67	10.013	299
Cremona	358955	202.75	-3.94	41.76	9.583	417
Brescia	1265954	264.54	-0.44	12.82	7.055	401
Pavia	545888	183.89	-6.91	48.91	4.751	412
Parma	451631	131.01	0.79	14.62	4.494	342
Pesaro	358886	139.77	-0.96	14.48	4.417	0
Sondrio	181095	56.67	-0.3	8.82	2.763	35
Aosta	125666	38.54	0.86	6.51	2.723	61
Lecco	337380	418.79	-3.08	56.45	2.572	282
Reggio Emilia	531891	232.15	-1.11	27.85	2.493	364
Alessandria	421284	118.38	-0.48	20.36	1.974	417
Trento	541098	87.18	-0.18	4.62	1.892	84
Biella	175585	192.26	-0.57	21.04	1.857	184
Novara	369018	275.34	-2.13	36.33	1.686	155
Rimini	339017	391.92	0.81	21.16	1.647	263
Verbania	158349	70.04	-0.88	13.85	1.560	45
Como	599204	468.49	-2.64	45.88	1.558	225
Modena	705393	262.43	0.71	22.69	1.529	383
Bolzano	531178	71.8	0.4	2.31	1.441	26
Vercelli	170911	82.11	-1.31	52.77	1.339	82
Massa	194878	168.78	-2.76	37.26	1.293	

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Milano	3250315	2063.05	6.12	38.17	1.276	405
Monza	873935	2155.69	-5.98	101.24	1.255	413
Mantova	412292	176.09	-1.43	29.31	1.225	343
Trieste	234493	1103.48	1.34	11.96	1.211	32
Fermo	173800	201.45	-1.05	27.93	1.143	
Ancona	471228	240.03	1.31	15.07	1.086	

Source: our elaboration from multiple datasets. See Appendix A and B for details.

* Days over law limits of PM10 + O3 (2017 – 2019); (1) Commuting index (inflows-outflows / population); (2) Commuting index (inflows+outflows / internal flows)

4.2. Air issues and policies

In this context of diffusion from top to bottom, geographical, climatic and air quality conditions played an important role and contributed to increasing the effects.

In particular, local climate changes such as temperature and humidity, poor air quality and the persistent absence of wind, make the Po Valley a one of a kind area, both at national and international level. Furthermore, frequent and persistent thermal inversion phenomena in the winter months, especially in periods of high atmospheric pressure, traps the cold air near the ground, together with the pollutants.

In the Po valley, urban phenomena of industrialization and intensive agriculture intertwine and more than 50% of national GDP is produced, as well as almost 50% of national energy is consumed [139]. The transition to compatible solutions related to well-being seems not exactly close, despite the several regional and national plans to monitor and improve air quality. In fact, on the occasion of the Covid-19 outbreak, PM10 emissions in the Po Valley were high and sometimes exceeded the limits and are to be related to the combined climate action - wind, winter thermal inversion - and activities as shown (Fig. 26).

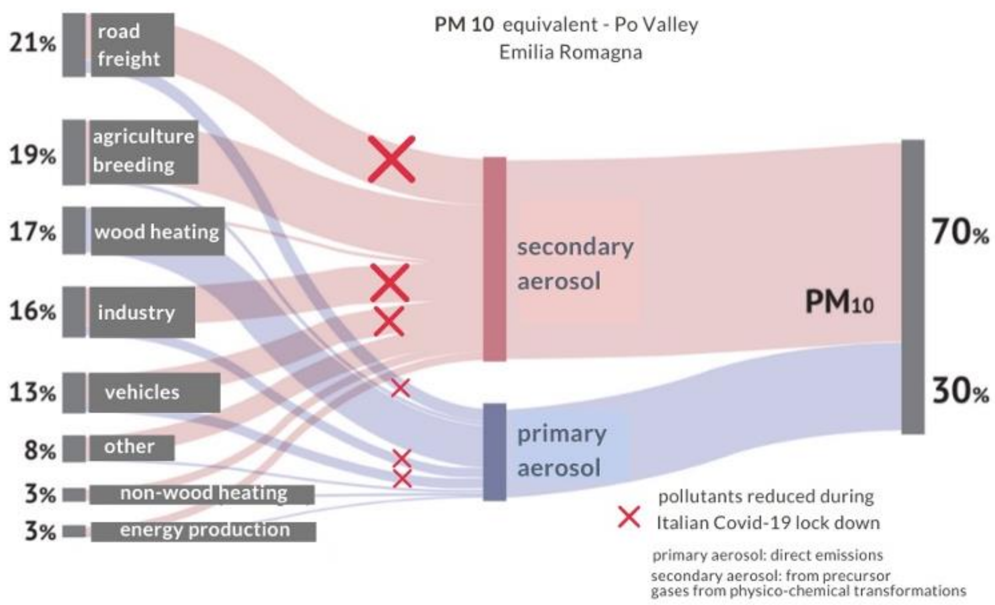

Figure 26. PM10 equivalent - Po Valley Emilia Romagna. Source: our elaboration from La qualità dell'aria Emilia Romagna, 2018

In this context, certainly not simple for both human, environmental and anthropic geography, the ecological approach has allowed us to obtain the first results and the first policy proposals with supported by LISA analysis (Fig. 27).

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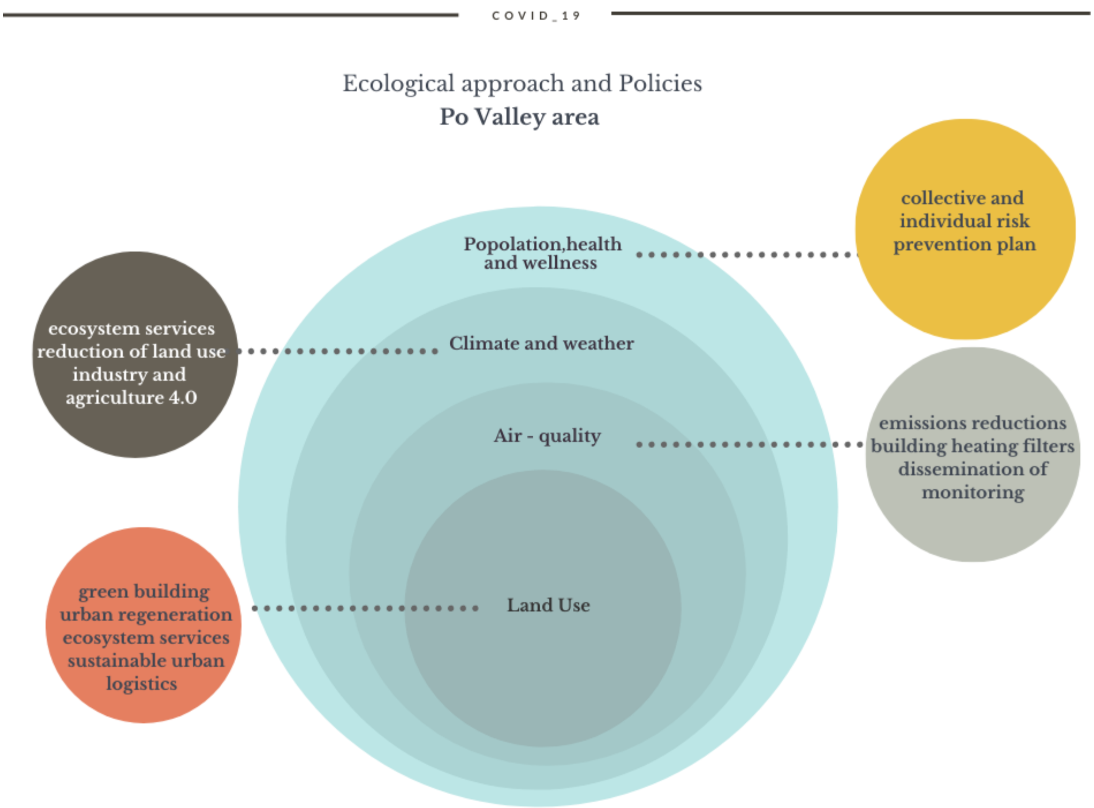

Figure: 27 Ecological approach and Policies - Po Valley Area. Our elaboration

The results produced are in line with the most recent scientific literature of the Po Valley and Covid 19 [140] [141] [142] and its guidelines: thinking globally and acting locally.

4.2. New approaches to planning and policies

Generally Plans are the results of long negotiations, which produce a long list of strict norms.

Consequently, the main aim of this approach to planning is to enforce such rules. In a lot of cases plans are old, very far from the current reality, or based on old laws, which do not allow the production of tools to answer current problems. The result is that the main planning goals are very far from providing a serious response to the transformation demands that daily arise.

This approach, based on vintage planning [133] or ghost planning [134], leads to a situation synthetized in left part of figure 28. The results are: a city with an uncontrolled real estate market, which produces urban sprawl; several portions of the city inhabited only by tourists, due to Airbnb effects; cities dominated by cars with a lot of pollution problems. This scenario leads to a consumption of resources greater than the capacity of the planet. In 2019 Overshoot Day occurred in late July. Consequently, for the following five months, the humankind used resources that the planet could not provide. An alternative is an approach based on simulations in assessing transformations impacts, allowing planners to take into account several land use scenarios, choosing the more suitable solutions for transformations. This approach to planning also considers possible losses of ecosystem services in simulations [143] [144] [145] [61] .

Several authors adopted the term Performance Based Planning [146] [147] [148] [149] [150] [151] [152] [153] to synthetize this approach. Consequently, this "umbrella" can contain all simulation models and tools. Due to data availability, all models based on Cellular automata or Multiagent Systems, Space Syntax, Geodesign [154] [155] [156], etc. can take into account a lot of components in detailed simulations. Therefore, goals of natural areas protection will be pursued more easily.

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Furthermore, adopting urban policies based on urban regeneration, sustainable mobility and the creation of green infrastructures [157] [158] [159] can create a more sustainable scenario able to flatten the curve under the earth carrying capacity [160] [161] [162].

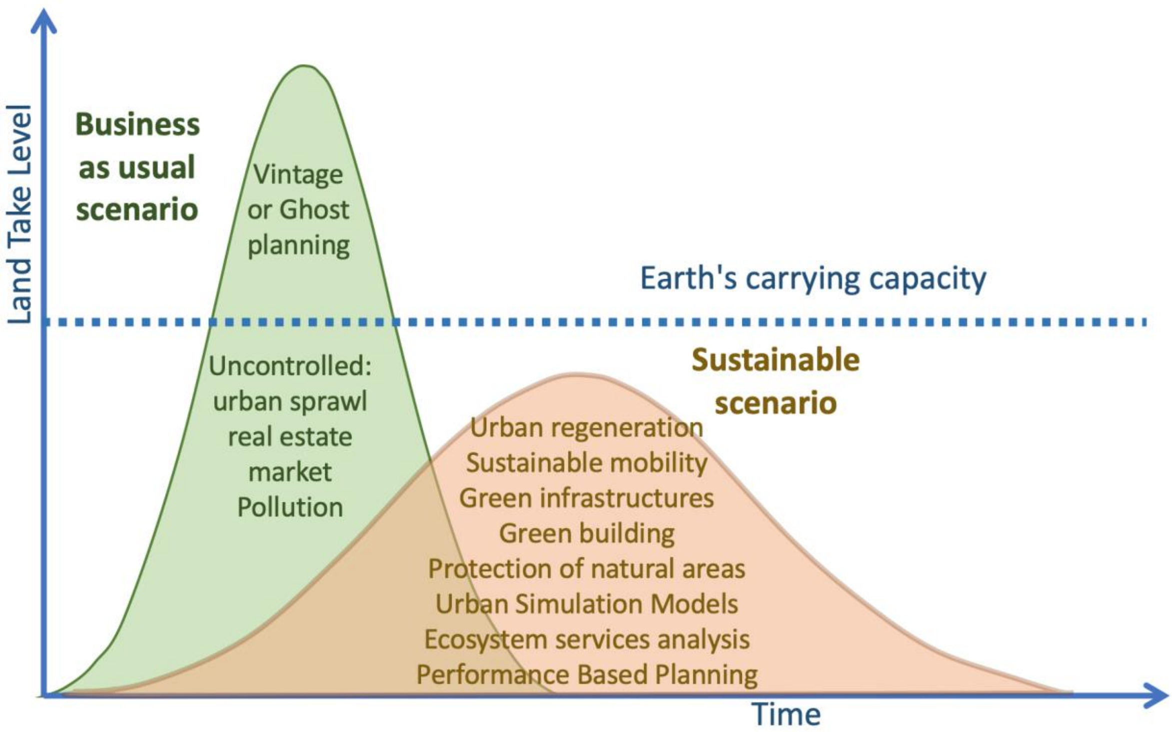

Figure 28. Flattening curve of earth's carrying capacity based in comparing two possible scenarios business as usual and sustainable.

5. Conclusions

In this paper we tried to find some possible answers to questions related to the hard Covid-19 outbreak that hit Italy as the first country in Europe after Southeastern Asian ones. In particular we tried to highlight some elements related to the causes of the development of virus hotbeds in Northern Italy - the Milan area and the Po Valley in particular - and on its diffusion in other part of the country. In such sense we analysed Covid-19 related data - cases and deaths - until 31 March 2020, in order to consider the situation at a suitable time after the hard lockdown policies set up by Italian government - 10 March 2020 - that, posing severe limitations to movement and production, should have stop the spreading of the disease, and therefore our observations can be considered in a 'freezed' situation of the diffusion.

As recent studies anticipated, multiple origins of the virus in Italy - through Germany, and directly in Italy from China, particularly in Lazio region - could be traced, but it is in the Po Valley area that the most severe outbreak took place, than spreading to other parts of Italy.

We observed similarities in the conditions of Wuhan area in Hubei Province, with those in the Po Valley metropolis, particularly related to the geographical and climatic conditions - presence of water bodies, flat lands, limited air circulation, similar climate zones -, socio economic ones - industrial production, transport infrastructure and mobility, population distribution and density -, as well as similarities in terms of presence, concentration and persistence of pollutants in the atmosphere.

We hypothesized the existence of relationships between pollution and both the spreading of the virus in generating outbreaks and lethality of the disease. In particular we took into consideration land take and air pollution, this latter referred to particulate (PM2.5 and PM10) and Nitrogen based components, as NOx and NH_3 deriving from human activities - industry, traffic, home heating; agriculture and cattle breeding. The idea was that the presence of air-related pollutants can generate

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a pressure on health conditions of population at risk and offer preconditions for both the development of respiratory related diseases and the complications, including some that are life-threatening, which may explain the excess lethality observed in the area under study. Also, particular atmospheric conditions in the early weeks of 2020 could have worsened the environmental situation in the areas - Wuhan and Po Valley -, as scarce precipitations and a winter warmer than the previous ones.

The analysis on Covid-19 related mortality showed a quite neat divider between Northern Italy on one side and Central and Southern Italy on the other side, following the Apennine mountain chain, with values higher - and much higher than expected - in the North and value in line with expected mortality in other Italian regions, particularly in the South. Starting from this we observed the spatial distributions of Covid-19 related deaths through SMR - Standardized Mortality Ratio - with climatic, pollutants and human-pressure indicators, finding evidences of similarities in the spatial patterns drawn with, in particular, $PM_{2.5}$ and other particulate, Nitrogen-related pollutants, land take, population density and commuting, mainly in the areas of Western Po Valley, in Milan area and its neighborhood toward the Provinces of Bergamo and Brescia, and in the South and Southeastern part, towards Emilia Romagna Region - Cremona, Piacenza, Parma, etc.

In terms of spatial diffusion processes in geographical terms, at global level we would have expected, hierarchically, a diffusion following the major air connections, and therefore outbreaks in areas of the World more connected to China, i.e., United States - Western Coast in particular - and Central and Northern Europe or, in the Italian case: furthermore, an outbreak following a diffusion process could have started in Lazio region - a direct flight existed between Wuhan Tianhe and Rome Fiumicino airports [163]. As geographers point out [80], an outbreak takes place where a susceptible population can be detected, and this, evidently, took place starting from the two hotbeds of Vo and Codogno, two municipalities in the Po Valley. Codogno, in particular, in Southern outskirts of the Metropolitan area of Milan is located at the center of three of the cities in Italy - Lodi, Cremona and Piacenza - having registered for consecutive years the highest ranks in terms of days per year of exceeding limits of particulate presence in the atmosphere.

Local, contagious and hierarchical diffusion processes could be hypothesized starting from such area, with more severe cases in Lombardy, Piedmont, Emilia Romagna and Marche Regions in particular, confirmed by the Covid-19 related Standardized Mortality Ratio computed over the all of the Italian provinces. The main legs of diffusion appear related to the main axis of gravitation of the Milan metropolitan areas: Westwards towards Piedmont bordering provinces, Eastwards towards the industrial cities of Bergamo and Brescia, South Eastwards towards Lombardy and Emilia Romagna regions - through to Marche region, along the 'Via Emilia'. Generally, the orientation seems to be compatible with the major communication routes - A4 and A1 motorways as well as the state road system. When observing Covid-19 outbreak in terms of mortality and cases' diffusion, however, a major incidence can be noticed particularly in the average density and dimension centers, more than in the major, denser cities. Denser and bigger regional capital cities as the same Milan, Turin, Verona and Bologna appear being relatively less affected than their neighboring, surrounding provinces, this element also apparently in contrast to a model of a hierarchical, top down diffusion from major centers towards minor ones. The deindustrialization of these capital cities, and their orientation towards an economy of services, could be related to that, as well as the different set up of social and human relations in the medium-size cities if compared with the bigger ones element, however, was not analyzed in the present research and needs further elaboration and analysis.

What has been raised therefore requires a profound reflection on the air emissions monitoring and in particular of the PM10, which did not substantially decrease during the lockdown. In fact, through monitoring it is possible to verify the effectiveness of the measures implemented at the local level to reduce air pollution. This caution should be included in the agreement of the Po Valley for the improvement of air quality, signed in Bologna during the G7 Environment of 9 June 2017, by the Minister of the Environment and the presidents of Lombardy, Piedmont, Veneto and Emilia - Romagna.

As regards to suggestions in terms of policies, we can strengthen the need to act towards policies aimed at the reduction of pollutants in the atmosphere, by means of speeding up the already existing plans and policies, aimed towards all the sources of atmospheric pollution: industries, home heating and traffic. That however does not appear sufficient if, as it was noticed through the satellite images - related pollution maps (ESA) before and after the lock down, the pollutants' reduction in the Po Valley area did not appear as dramatic as expected, demonstrating an inertia of pollutant in air, due to climate and geographical conditions of the area. Investment in clean transport and building should therefore be reinforced, starting also from rapidly applicable measures - road washing; pollution eating paints, facades and plants, etc.

The results so far obtained, as well as the conclusions hypothesized so far, need to be better studied and understood with further data, at present still not validated and available. In particular more observational studies based on individual complete data related to the Covid-19 cases and deaths, registered also at a finer geographical scale than the regional and provincial ones, would allow to overcome the intrinsic limit of the use of provincial units for data collection, in terms of heterogeneity of their shape and population. We need also to better analyze the overall amount of data and indicators collected so far, also in terms of the evolution of the virus outbreak and its hoped reduction, and in the light of the other results obtained in medical and epidemiological research by other research groups.

Author Contributions: The paper is the result of the common reflections, research and work of the authors involved. However, Abstract and section 5 - Conclusions are in common to GB, GB, PC, MD and BM. Section 1.1 can be attributed to PC and MD; Section 1.2 to GB (Giuseppe Borruso), 1.3 to GB (Ginevra Balletto). In Section 2, subsection 2.1.1 has been realized by GB (Giuseppe Borruso) and GB (Ginevra Balletto), subsection 2.1.2 by BM, and subsection 2.1.3 by GB (Giuseppe Borruso). Subsection 2.2 has been supervised by GB, GB and BM. Subsection 2.3.1 was treated by GB (Giuseppe Borruso), subsection 2.3.2 and 2.3.3 by MD and PC. Subsection 2.3.4 was realized by GB (Giuseppe Borruso) and BM. In section 3, subsection 3.1 is to be attributed to GB (Giuseppe Borruso), subsection 3.2 to GB (Ginevra Balletto) and subsection 3.3 to BM. In Section 4, subsection 4.1 is to be attributed to GB (Giuseppe Borruso), subsection 4.2 to GB (Ginevra Balletto) and subsection 4.3 to BM. Cartographic elaborations have been realized by Giuseppe Borruso (Figures 2, 4, 10, 11, 14, 15 and 25; Appendix D) using QGIS 3.10. LISA maps were realized by Beniamino Murgante (Figures 12, 13, 16, 19, 20, 21, 22, 23 and 24; Appendix C) using GeoDa. Ginevra Balletto realized Figures 1, 3, 9, 17, 18, 26 and 27, edited data in Appendix A and B. Figures 5, 6, 7 and 8 are authors' elaborations from Haggett [85] and Cliff and Haggett [79]

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Appendix A

Table A1. Data sources for Covid-19 research

Data / Index	Source	Link
Motorization rate of motorcycles - No. of motorcycles in circulation / 100 inhabitants Motorization rate of cars - No.of cars in circulation / 100 inhabitants	ACI 2019	http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche.html
PM10 - 2019 PM10 - 2020	EEA 2020	https://www.eea.europa.eu/themes/air/air-quality-and-covid19/monitoring-covid-19-impacts-on
% humidity - Il meteo.com Weather archive Jan-Feb-Mar 2020 Km/h wind - Il meteo.com Weather archive Jan-Feb-Mar 2020	Il METEO 2020	https://www.ilmeteo.it/
Standardized mortality rate - per 10.000 inhabitants PM10 - Annual average values in µg/mc Asthma, diabetes and hypertension drugs - per capita Hospital emigration - % No. of discharges of residents outside the region Cancer mortality - per 1000 inhabitants / 5 years Acute myocardial infarction mortality - per 1000 inhabitants / 5 years	Il SOLE 24 ORE 2019	https://lab24.ilsole24ore.com/qualita-della-vita/classifiche-complete.php

Data / Index	Source	Link
Climate well-being index 2008-2018 Relative humidity - annual days outside climatic comfort >70% or <30% Wind gusts - annual days with gusts > 25 knots Rains - annual rainy days Extreme events - annual days with accumulation > 40 mm Heat waves - Overheating per year > = 30 ° C for 3 consecutive days Summer breeze - average daily knots of wind in		https://lab24.ilsole24ore.com/indice-del-clima/indexT.php

the season Fog		
Total green (urban green + protected areas net of overlaps) -% Natura 2000 sites - Total No.		http://www.ost.sinanet.isprambiente.it/Report_indicatorismry.php?cmd=search&sv_Tema=Infrastrutture+verdi&sv_IIP=Numero+totale+di+siti+Natura+2000+%28ZPS-SIC-SIC%2FZPS%29&sv_Atag=Comune&sv_Anno%5B%5D=2017
Protected natural areas -% on the municipal surface area	ISPRA 2017-19	
Nitrogen oxides (NO+NO_2) - Mg by province Carbon monoxide (CO) - Mg by province Carbon dioxide (CO2) - Mg by province Nitrous oxide (N_2O) - Mg by province Ammonia (NH3) - Mg by province PM10 - Mg by province PM2.5 - Mg by province		http://www.sinanet.isprambiente.it/it/sia-ispra/inventaria/disaggregazione-dellinventario-nazionale-2015/view

Data / Index	Source	Link
Soil consumption 2019	ISPRA 2017-19	http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/il-consumo-di-suolo/i-dati-sul-consumo-di-suolo
Temperatures - average value 2007-2016	ISTAT 2019-20	https://www.istat.it/it/archivio/temperature
Resident population on 1 January 2019 Resident population 2019 > 65 years		http://demo.istat.it/
Population density 2019 - No. / Kmq		http://demo.istat.it/pop2019/index3.html?fbclid=IwAR3ZfOAubR1OBU3xD5qvD5FKWMhKW9Cxy1KF68GCZMJxgnIy1SIe4MJlrEI
Commuting (O/D) 2011		https://www.istat.it/pendolarismo/grafici_province_cartografia_2011.html
Industrial production		https://www.istat.it/it/archivio/produzione+industriale
Cycle paths- Km NO_2 - Annual average values in μg/mc	LEGAMBIENTE	https://www.legambiente.it/wp-content/uploads/rapporto-ecosis

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Trees in the city - No. of trees in public areas / 100 inhabitants	2019-20	tema-urbano-2019.pdf
Efficient land use - index 0 -10		
Cycle paths - m/100 inhabitants		
PM2.5 - Annual average values in µg/mc		
NO_2 - Annual average values in µg/mc		
Ozone (O3) - No. of days to exceed the 8 hour moving average of 120 µg / mc		
PM10 + Ozone - overrun days 2017-2019 h		https://www.legambiente.it/wp-content/uploads/2020/01/Malaria-di-citta-2020.pdf
PM10 - overrun days 2015-2019		

Data / Index	Source	Link
COVID-19 cases - No. by province	ITALIAN MINISTRY OF HEALTH 2020	http://www.salute.gov.it/portale/nuovocoronavirus/dettaglioContenutiNuovoCoronavirus.jsp?lingua=italiano&id=5351&area=nuovoCoronavirus&menu=vuoto
Global climate change	NASA 2020	https://climate.nasa.gov/climate_resource_center/interactives
COVID-19 cases - No. by Region and Province	DPC 2020	http://www.salute.gov.it/portale/nuovocoronavirus/dettaglioContenutiNuovoCoronavirus.jsp?lingua=italiano&id=5351&area=nuovoCoronavirus&menu=vuoto
COVID-19 Bulletins	ISS 2020	https://www.epicentro.iss.it/
Report - issue 1-3	WHO 2020	http://www.emro.who.int/health-topics/corona-virus/situation-reports.html

Data / Index	Source	Link
VIEWERS		
Flight Connections	REAL TIME	https://www.flightconnections.com/
Flight Radar 24		https://www.flightradar24.com/

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Marine Traffic		http://www.marinetraffic.com
Weather		https://www.ilmeteo.it/
Wind		https://it.windfinder.com/
Air quality		https://aqicn.org/map/italy/
Air quality		https://www.nytimes.com/interactive/2019/12/02/climate/air-pollution-compare-ar-ul.html
Air quality		https://waqi.info/it/
Air quality		https://breezometer.com/air-quality-map/
DASHBOARD		
Civil Protection Department		http://opendatadpc.maps.arcgis.com/apps/opsdashboard/index.html#/b0c68bce2cce478eaac82fe38d4138b1
WHO		https://who.sprinklr.com/
CORONAVIRUS RESOURCE CENTER		https://coronavirus.jhu.edu/map.html
#IOCONTO		https://www.ioconto.org/
WORLDOMETER		https://www.worldometers.info/coronavirus/
TABLEAU		https://www.tableau.com/covid-19-coronavirus-data-resources
IL SOLE 24 ORE	COVID LIVE	https://lab24.ilsole24ore.com/coronavirus/

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Appendix B

Table B1. - Data and indicators used in the LISA

Data / Index	Cov_	Source	Data origin	Unit
Soil consumption 2019, total 2014-2018 - ha/mq	3	ISPRA 2019	http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/il-consumo-di-suolo/i-dati-sul-consumo-di-suolo	provincial
Pm 2.5 - average yearly values - µg/mc	14	ISPRA	http://www.isprambiente.gov.it/	urban/peri urban
Pm 10 - average yearly values - µg/mc	15	Il SOLE 24 ORE 2019	https://lab24.ilsole24ore.com/qualita-della-vita/classifiche-complete.php	urban/peri urban
Ozone (O_3) - days exceeding mobile average on 8 hours - 120 µg/mc	19	ISPRA	http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/il-consumo-di-suolo/i-dati-sul-consumo-di-suolo	urban/peri urban
Cases of Covid-19 - n per Region and Province 15 April /2020	20	PROTEZIONE CIVILE 2020		provincial
Ammonia (NH_3) - Mg	25	ISPRA 2017	http://www.sinanet.isprambiente.it/it/sia-ispra/inventaria/disaggregazione-dellinventario-nazionale-2015/view	provincial
Hospital emigration	33	IL SOLE 24 ORE 2019	https://lab24.ilsole24ore.com/qualita-della-vita/classifiche-complete.php	urban
Drugs per capita: asthma, diabetes and hypertension	70	Il SOLE 24 ore 2019	https://lab24.ilsole24ore.com/qualita-della-vita/classifiche-complete.php	urban
Climate well-being index	37	Il SOLE 24 ore 2019	https://lab24.ilsole24ore.com/indice-del-clima/	urban
Wind gusts, annual days with gusts> 25 knots	39	IL SOLE 24 ORE 2019	https://lab24.ilsole24ore.com/indice-del-clima/	urban
Fog	41	IL SOLE 24 ORE 2019	https://lab24.ilsole24ore.com/indice-del-clima/	urban
Surface waterproofed to year 2016 (source ISPRA)	49	ISPRA	http://www.isprambiente.gov.it/it/ispra-informa/area-stampa/dossier/consumo-di-suolo-2017	
Urbanized areas	52	Papers By		

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early 2000s		Romano et al. reported in references		
Km/h wind - Il meteo.com Meteo archive - Jan - Feb - Mar 2020	55	IL METEO.it 2020		urban/peri urban
Deaths	57	Different sources	31-03-2020	provincial
Contagions - Country's Total. Ministry of Health 03-31-2020	58			provincial
Population / Km^2	64	ISTAT 2019	http://demo.istat.it/pop2019/index3.html?fbclid=IwAR3ZfOAubR1OBU3xD5qvD5FKWMhKW9Cxy1KF68GCZMJxgnIy1SIe4MJlrEI	provincial
Lethality - Ministry of Health 03-31-2020	65			
SMR	66	Our elaboration		provincial
PM10 + Ozone - overrun days 2017-2019 h	72	LEGAMBIENTE 2020	https://www.legambiente.it/wp-content/uploads/2020/01/Malaria-di-citta-2020.pdf	urban/peri urban
CO_2 / non urbanized areas	82			
Commuting: OD flows / internal flows	83	ISTAT 2011 (census data)	https://www.istat.it/pendolarismo/grafici_province_cartografia_2011.html	urban/peri urban

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Appendix C

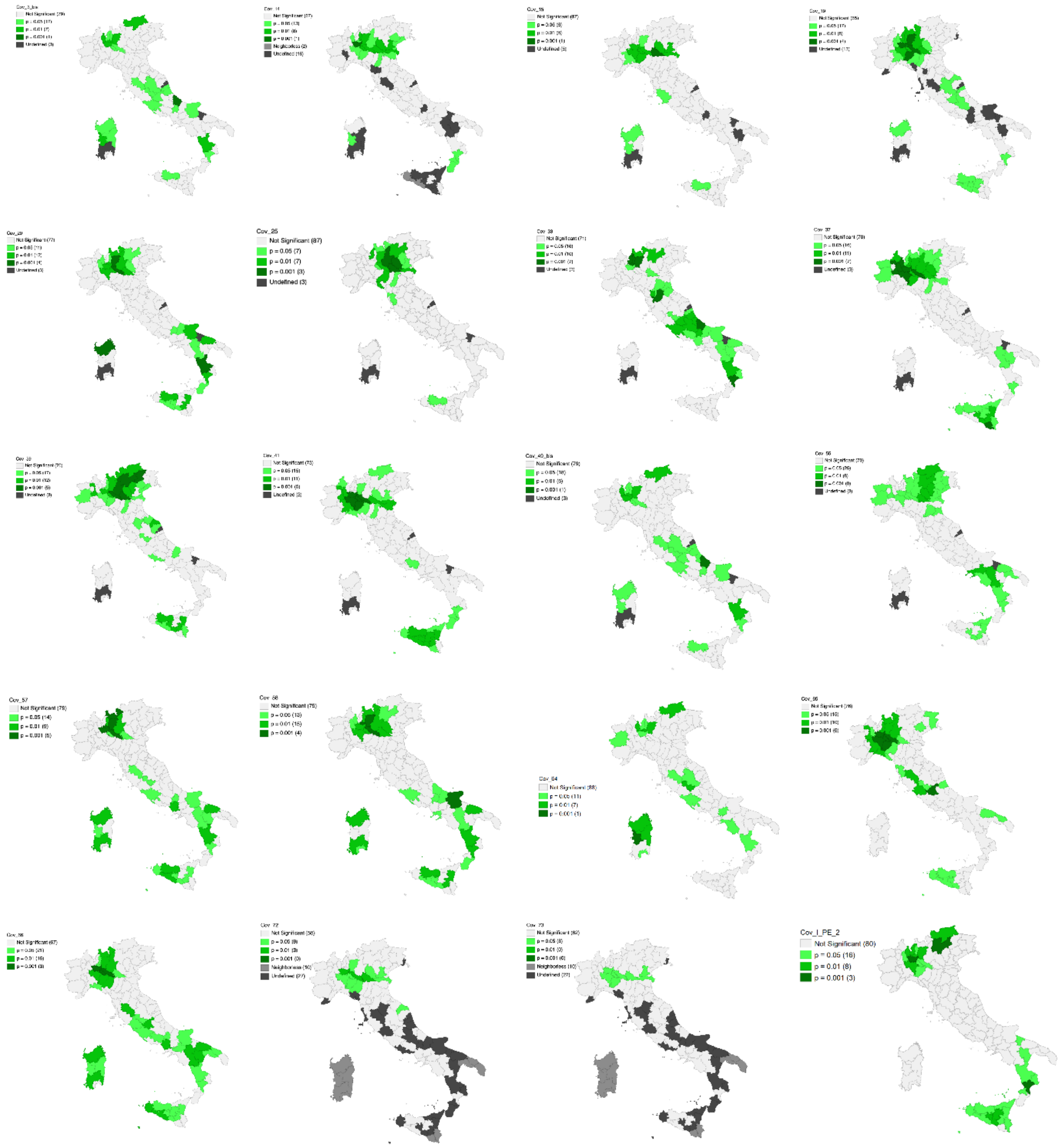

Figure C1. P-Values on variable used in the LISA analysis (see Table A2 in Appendix A). Variables: 3 – 72. Source: Our elaborations from data on Table A1 and A2 with GeoDa (https://geodacenter.github.io/)

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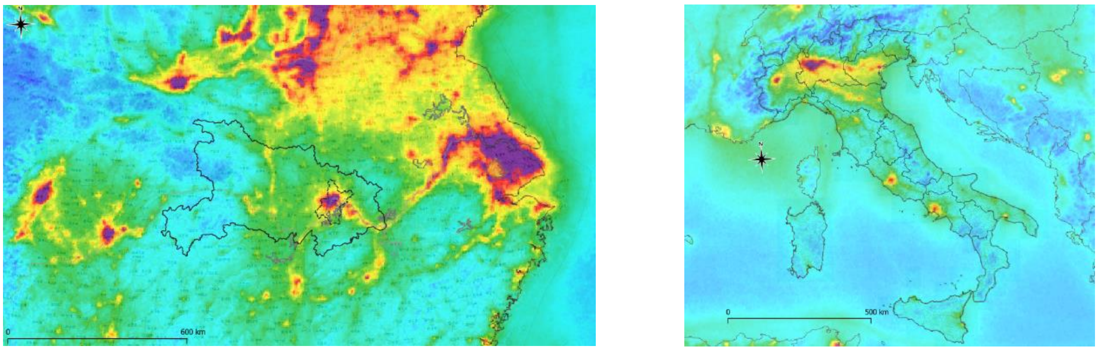
Appendix D



(a) (b)

Figure D1. ESA Nitrogen dioxide pollution and selected areas.: (**a**) Hubei Province in China with Wuhan Metropolitan areas; (**b**) Italy and Administrative Regions. Lombardy (Top Centre) with highest level of pollution.

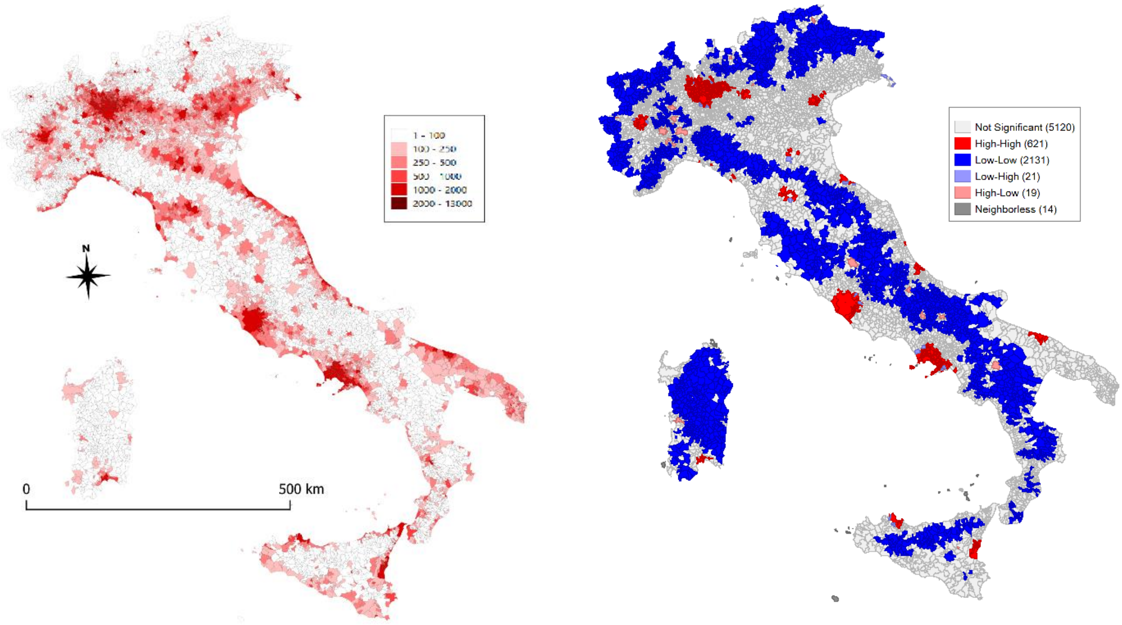


Figure D2. (**a**) Population density in Italian Municipalities; (**b**) LISA map on Population density in Italian Municipalities. Source: Our elaborations from ISTAT population data 2019 (http://demo.istat.it)

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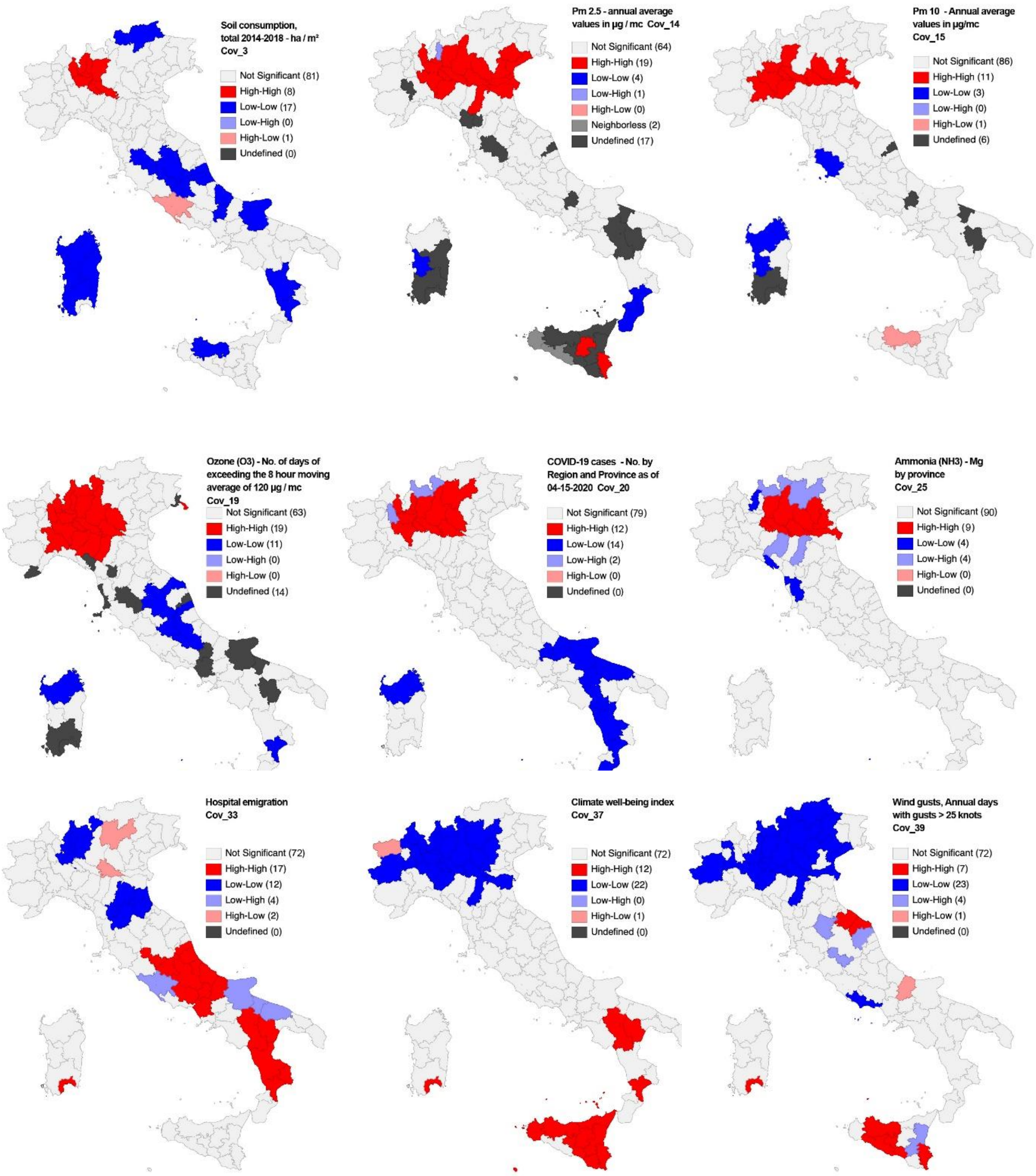
Appendix E



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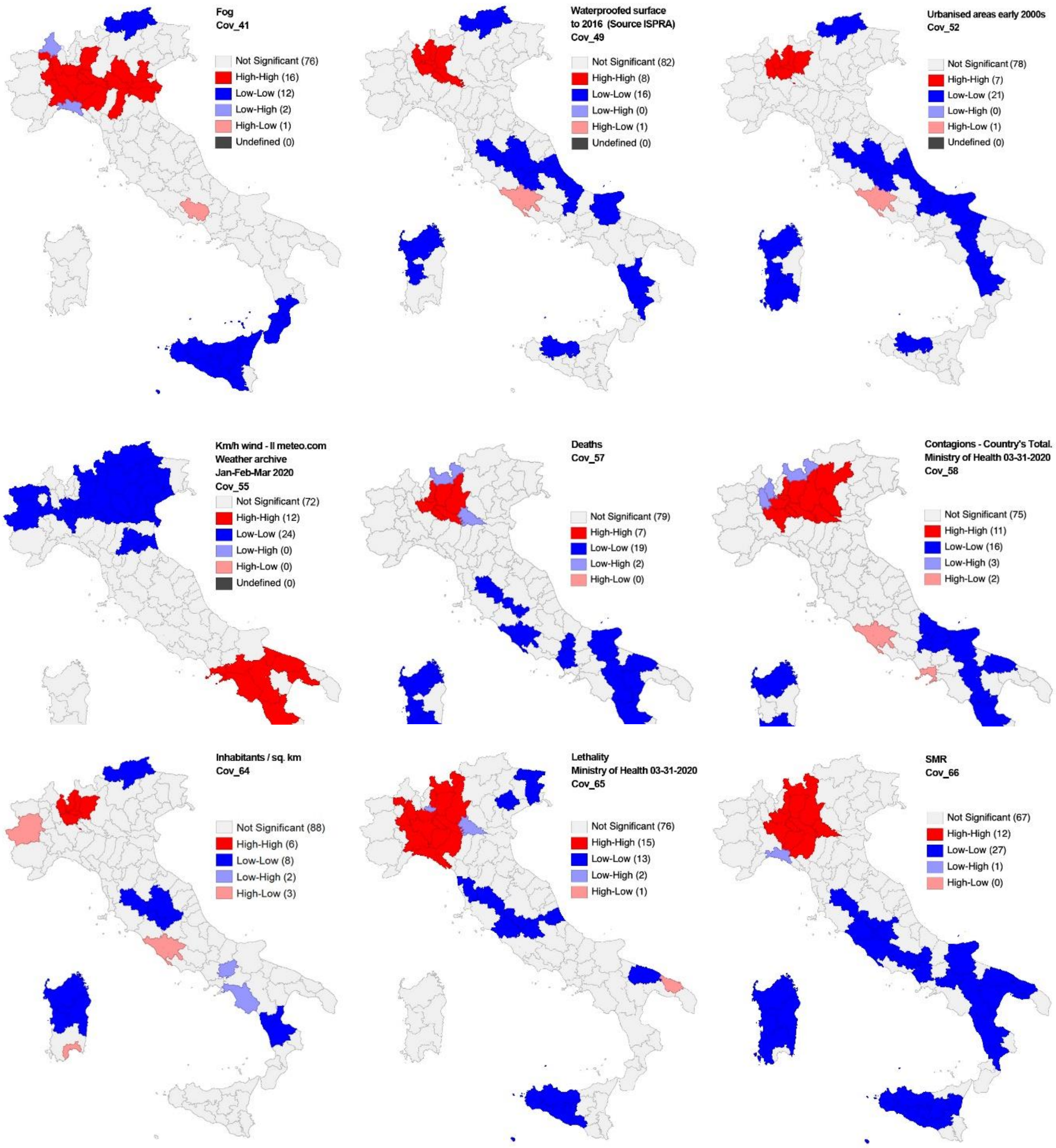

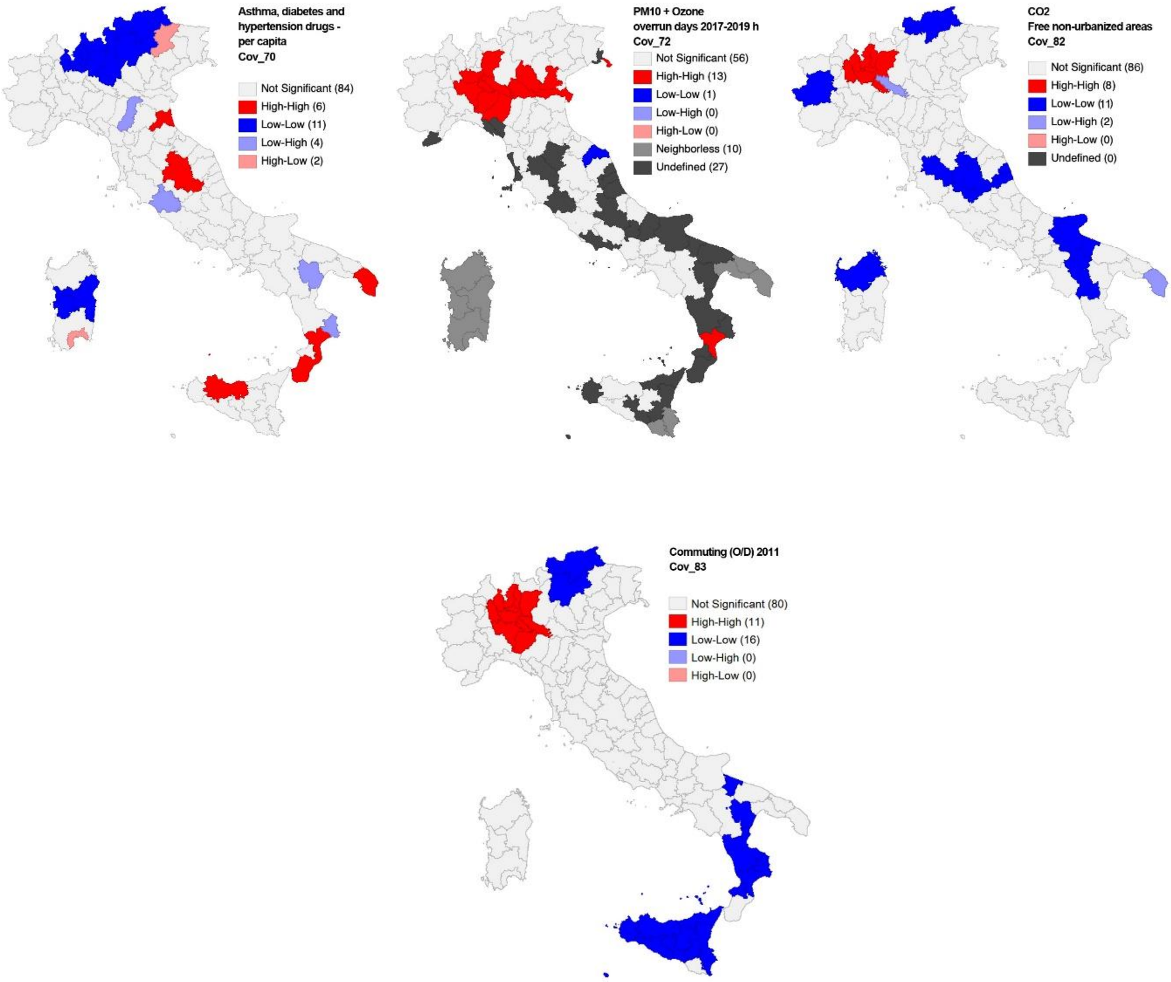

Figure E1. LISA maps on variables 3 - 83 used in the analysis (see Table A2 in Appendix A). Source: Our elaborations from data on Table A1 and A2 with GeoDa (https://geodacenter.github.io/)

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