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

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Climate variation in metropolitan cities

Spatial self-containment, contiguity and space-time relations in Cagliari urban area (Sardinia, Italy)

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Abstract

Climate has always been studied in cities, where strong relations can be found with urban form and spatial patterns. Temperature variations, heat islands and floods are among the main factors to represent climatic phenomena and related changes over time. The same urban location choices come out from the need to resist adverse events. In general, the urban form can be related to climatic conditions, both to benefit from positive externalities - healthiness, sun exposure, ventilation, water supply - and to reduce negative externalities - thermal stress, heavy rainfall and heat islands. Furthermore, urban development, particularly attributable to land take, put in evidence how the European, and particularly the Italian, urban system presents 56% of population settled in urban areas with a high value of sealed surfaces and limited green areas, so that urban centres are more and more characterizing as climate change hotspots. In this framework the hereby presented research is developed, focused on the observation of the temperature variations in urban areas in time, aimed at capturing the changes occurring also considering the spatial extent and form of the cities more vulnerable to such phenomenon. The research in particular was aimed at exploring possible different ways of aggregating areas to a proper urban dimension: in particular Metropolitan Cities (MC) and Labor Market Area (LMA) in order to identify the most suitable geographical dimension both for the observation of the phenomenon and for the policy targets of climate neutrality. This is done analysing the spatial autocorrelation of climate-related variations in space and time.

Keywords

Climate variation; Metropolitan city; Labour Market Areas; LISA; Spatial Autocorrelation.

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1. Introduction

Climate has always been a phenomenon observed and studied in cities, in which there are deep correlations with the relative shape and spatial distribution (Kellogg & Schwarz, 2019). Temperature increase, heat islands and hydraulic floods are the main factors of representativeness of the climatic phenomena and its change over time. The urban localization, shape and spatial distribution are strongly related to climate, on the one hand to derive greater benefits and positive externalities: healthiness, sun exposure, ventilation, water and on the other to minimize the negative externalities: thermal stress, intense precipitation, and heat islands (Koop & van Leeuwen, 2017; Papa et al., 2014). In particular, the urban location choices arise from the important need to resist adverse events such as hydraulic floods, while the high temperatures have been addressed by means of a dense urban system able to shade and create thermal currents of air to dissipate heat (Salvati et al., 2019). Urban forms developed in the past, even in hot and arid climates, were organized to mitigate the temperature. An important example is the city of Yazd in Iran, where the use of towers about 30 meters tall performed the function of generating air currents able to counteract the heat, removing hot air from inside the building during the day and letting in fresh air from outside during the night. Underground water tanks further cooled the air. Furthermore, since ancient Greece, the urban form has been compact, so as to avoid direct solar radiation as well as the ability to reflect sunlight, rejecting the sun rays in the streets and at the same time thus reducing the formation of heat in the urban spatial organization. In other periods, in the cities of the Renaissance, pools of water and fountains were proposed with a double function, aesthetics and as a heat exchanger for cooling. While climate has driven the obstruction of the city, the latest climate change has become one of the most significant threats to world heritage properties, potentially impacting their Outstanding Universal Value, including their integrity and authenticity, and their potential for economic and social development at the local level [1]. Nonetheless, compared to pre-industrial levels, the average temperature of the planet has increased by 0.98° C and the trend observed since 2000 suggests that, in the absence of interventions, it could reach +1.5° C between 2030 and 2050 [2]. Indeed, despite the progressive international commitments (Kinley et al., 2021; UNFCCC, 2015; UNFCCC, 2020) aimed at reducing the emission of greenhouse gases, overall CO_2 emissions have increased, while in Italy a decline has begun on the occasion of the 'double dip', global financial and internal debt crisis (Accetturo et al 2022). In Italy, the trend in the intensity of carbon dioxide emissions over the course of almost 20 years has declined and is partly attributable to the production of energy from renewable sources (hydroelectric, wind and solar) and to the increase in energy efficiency in the residential, tertiary and industrial sectors (Andreoni & Galmarini, 2012) (Fig.1).

In particular, 56% of the population is concentrated in European and Italian urban systems; in urban contexts with high impermeable surfaces, limited green areas and a gradual increase in temperatures (Cobbinah, 2021; Fan et al., 2021). In this synthetic framework, the present work aims to observe the climate and temperatures' patterns in two geographic dimensions: the Italian metropolitan cities (MC) and the Labour Market Area local (LMAs, "Local Labour Systems – SLL" in Italy).

In particular: i) the MC, as defined by law (Law 7 April 2014), includes a large core city and the smaller surrounding municipalities belonging to a same wide interconnected area, with regards to economic activities and essential public services, as well as to cultural relations and to territorial features - in Italy in most of the cases MC are evolution of provinces, therefore based on an administrative rather than a functional principle. In the case of the MC of Cagliari, its set up as a set of interconnected municipalities is mainly based on functional principles; ii) system of municipalities are grouped on the basis of commuting movements, therefore representing a 'homogeneous' system of relationships among living and working places. The concept of LMA wants to bring light to the effects of commuting on the labour market centres and their hinterlands. This should assist further in the urban planning policies, while being based on relevant statistical evidence. The LMAs represent a geographical dimension to observe and to address new perspectives in terms of analyzes and studies and therefore also a powerful policy tool. From the functional point of view this represents an interesting aggregation to study phenomena considering the metropolitan connections.

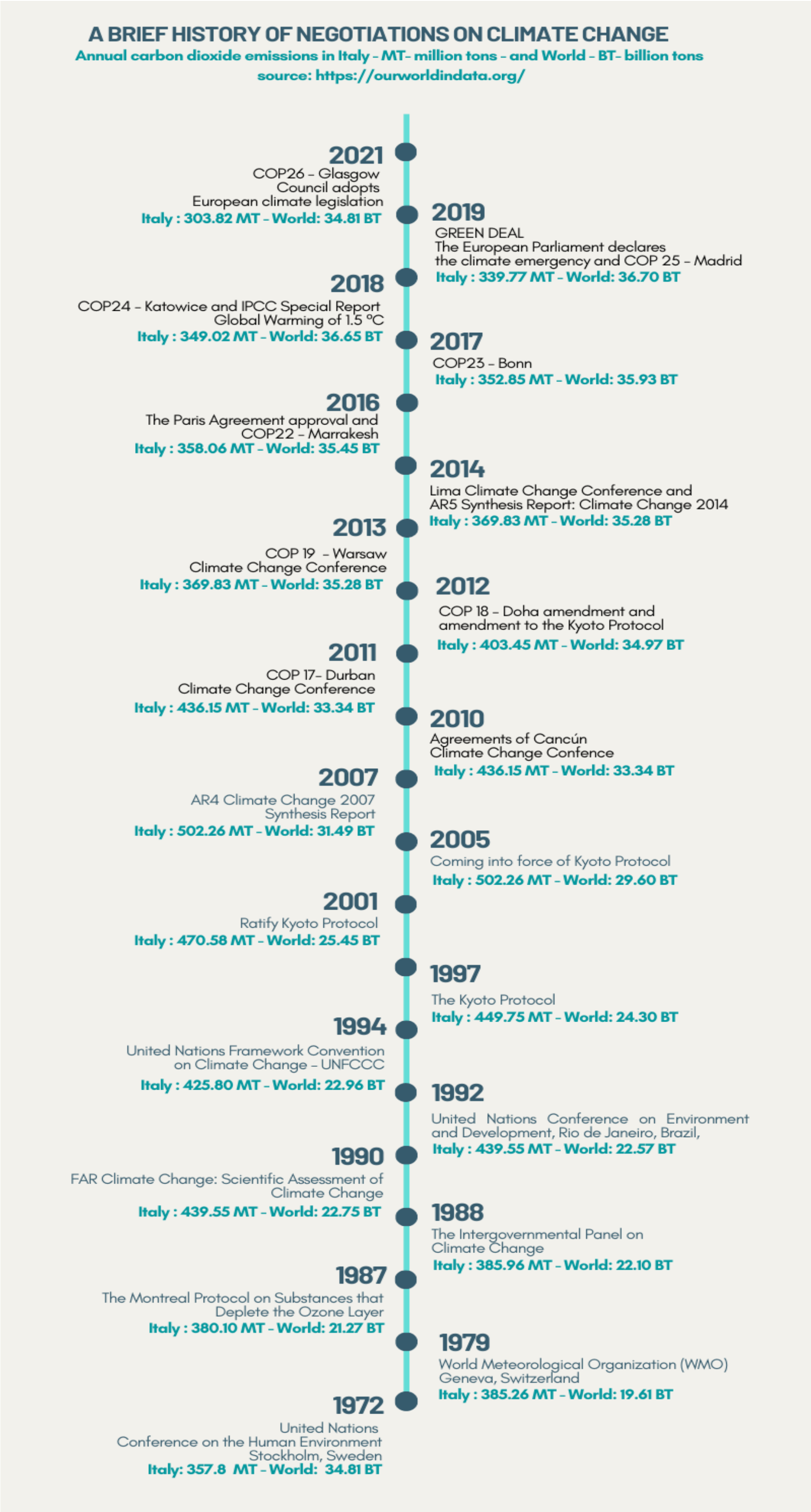


Fig.1 Major conferences and events on environmental and climate issues (Italy and Word)

The observation of the phenomenon was concentrated in the MC and LMA of Cagliari (case study) considered a representative Italian case (Ferguson, 2022; Palumbo et al., 2020) (Fig.2).

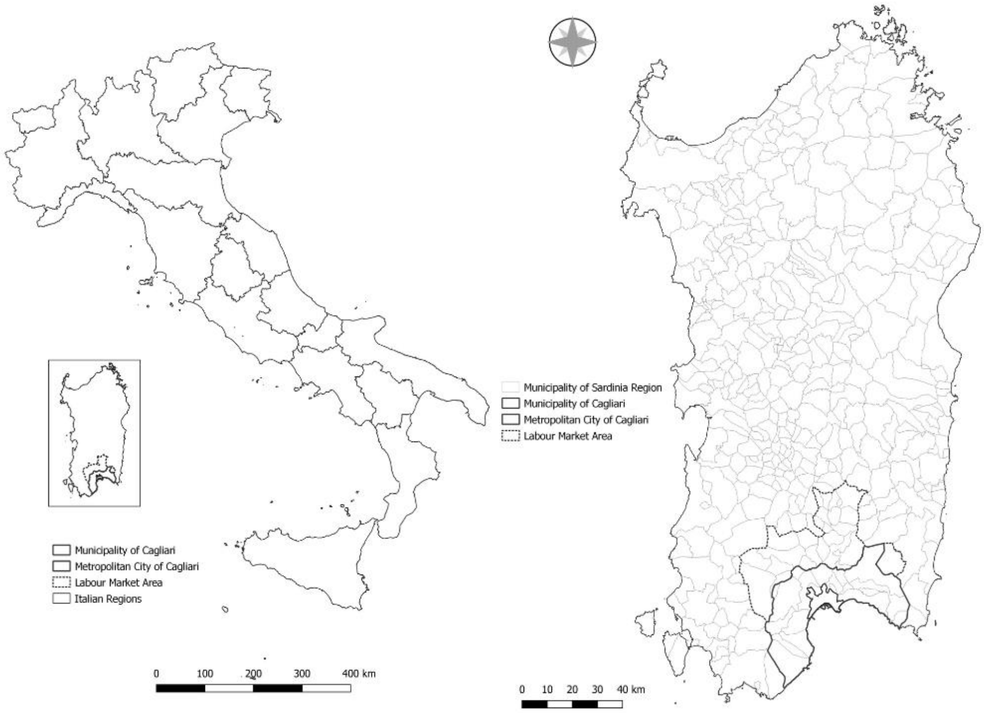


Fig.2 Geographical focus. Sardina Region in Italy and the units of analysis (Cagliari Metropolitan City and Labour Market Area)

The contribution is not intended to be exhaustive, rather to draw attention to possible interpretations of the phenomenon 'Climate variation analyzed through the territorial dimension of spatial self-containment, contiguity' and commuting (LMA).

The paper is organized as it follows:

Paragraph 2 Materials and Methods; 2.1 Temperature increase and human factors, which anticipates the relationship between temperature increase and vulnerability of some segments of the population; 2.2 Metropolitan City (MC) and Labour Market Area (LMA), which describes the territorial dimensions (CM and LMA) on which the observation of the thermal phenomenon is based; 2.3 Methodology: Spatial dimension (MLA and MC) and Spatial representation; paragraph 3: Case study of Cagliari: Metropolitan City (MC) and the Labour Market Area (LMA), Sardinia, Italy; paragraph 4 and 5: Results and Discussion and paragraph 6: Conclusions and future development.

2. Materials and methods

2.1 Temperature increase and human factors

The 21st century presents new urban challenges, in Italy in particular, which combine local and global issues. Complex challenges arise, such as the need for renewed economic growth, contextual to the gradual aging of the population, environmental degradation and the consumption of resources: energy, water, land take (Dameri et al., 2019; Di Febbraro et al., 2019).

Furthermore, the city, as a spatial organization with a high anthropogenic concentration – residence, production / services and mobility – is also a vulnerable place for thermal variations such as the Urban Heat Island - UHI which depends on the characteristics of the building materials, bituminous roads and greenhouse gas emissions (Susca, 2020).

Furthermore, UHIs ranking in size – from hundreds of square meters to hundreds of square kilometers – often persist in contexts characterized by widespread demographic aging processes that make large sections of the population vulnerable (Gonzalez-Trevizo et al., 2021). Necessarily, the Human Factor constitutes a problem to which it is essential to find an immediate solution to mitigate these effects – Human Solution (Dwivedi et al., 2022). In fact, the forecasts suggest worrying scenarios such as the increase in global temperature from 2 to 4° C over a period of about forty years, with greater increases in urban contexts, which would require systematic monitoring aimed at mitigation (Balletto et al., 2018; Marando et al., 2022; Morabito, et al., 2021). This increase is worrying both for sensitive communities (over 65) and for the progressive vulnerability extended: buildings, roads, monuments and water and food distribution networks (Phelps, 2021).

2.2 Metropolitan City (MC) and Labour Market Area (LMA)

In consideration of future scenarios, analyzing and evaluating thermal variations represents one of the most complex challenges for the preparation of climate adaptation policies.

An important consideration needs to be carried on before addressing the topics at stake in the present paper, such as the arrangement of the metropolitan areas, and its interpretation from the different points of view. Although metropolitan cities were created to ensure better management of the territory and urban phenomena with a supra-municipal dimension, nevertheless they represent vulnerable contexts due to the increase in temperatures partly attributable to land consumption which in the 14 metropolitan cities have shown an overall increase since 2016 21.4% of land consumed (about 5,000 km^2 compared to about 23,000 km^2 on the entire national territory) (Romano, 2017). In this synthetic framework, the Metropolitan City of Cagliari represents an important case of methodological experimentation, other than representing a nearly unique case in the Italian intermediate administrative framework, of a metropolitan city designed more on a functional basis than on an administrative one. In fact, for this target area of Cagliari, the climate projections show a significant increase of the temperature minimum, maximum and average temperature increase (from +1.3° C to +3.6° C). This confirms the strong increase in hot extremes such as tropical nights and summer days (+ 22-40 days) and a slight general reduction in total rainfall. The significant increase of the temperature (min - max) and the strong increase of the hot extremes of Cagliari represents the most significant case of all the Italian metropolitan capital cities, also in terms of exposed population. The temperatures are extracted from the open database (https://climatechange.europeandatajournalism.eu/) built by OBC Trans Europa for EDJNet, that takes into consideration the temperature data of over 100,000 municipalities in 35 European countries. The average values of the 1960s were compared with those of the period 2009-2018, in order to detect the extent of global warming in each local community. Data is taken from Copernicus and the European Center for Medium-Range Weather Forecasts (ECMWF).

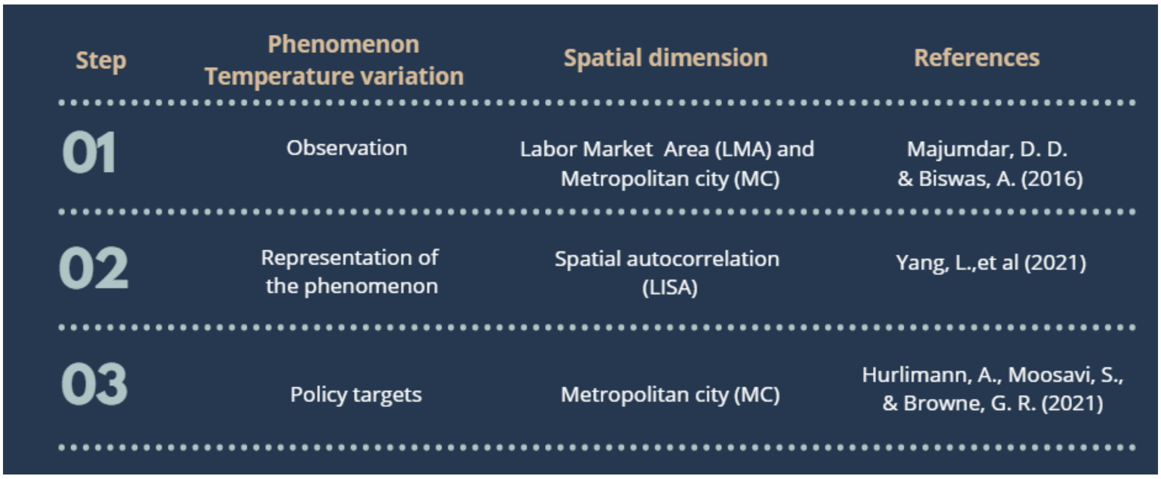
The data provide estimates of the temperature two meters above the ground and refer to a grid of cells measuring 5.5x5.5 km. The raw data were processed to obtain for each cell the values of the average annual temperature estimated in the two decades taken into consideration (1961-1970 and 2009-2018), in order to calculate the variation that took place. Each European municipality was then associated with one of the cells of the grid, also considering the urban density and the conformation of the coastline.

The land temperature observation scale was municipal aggregated by metropolitan cities (MC) and by the Labour Market Area (LMA). According to ISTAT (Italian National Institute of Statistics), LMA means a territorial area whose boundaries, regardless of the administrative articulation of the territory, are defined using the flows of daily home/work trips (commuting). In the LMA the population resides and works and exercises most of the social and economic relationships, home / work trips are used as a proxy of the relationships existing in the territory. From that point of view, an LMA can be considered as the catchment areas or the hinterland of the central place of the unit itself.

The evaluation of temperature proposal therefore refers both to an administrative dimension (that of governance of the metropolitan city - MC) and to a non-administrative dimension, representative for describing the phenomenon (LMA). In other words, the observation of the phenomenon of increasing temperatures on the LMC scale allows it to represent the phenomenon in its complexity, unlike the MC scale: this, nevertheless, represents the territorial dimension of the governance of complex urban phenomena.
The temperatures, on the other hand, were analyzed by spatial autocorrelation, applying the local Moran's I, using the open GEODA software, in line with the territorial dimensions (LMA and MC) respectively representative of the proxy of the relationships existing in the territory (self-containment, urban contiguity, and governance).
The population vulnerable to climate change (over 65), on the other hand, it was extrapolated from Climate Change 2022: Impacts, Adaptation and Vulnerability [[1]], which highlights how in Italy the population aged 65 and over compared to the total population is 23.8%, which also represents the highest percentage among European Nations, which in 2042 according to ISTAT will be 34% of the population.

2.3 Methodology: Spatial dimension (MLA and MC) and Spatial representation

The proposed method consists in the observation of the phenomenon of temperature variation (space - time) through two geographical dimensions LMA, representative of urban dynamics and the urban administrative dimension MC, less representative for observation, but central in achieving the political objectives of climate neutrality (Hurlimann et al., 2021). The representation of the phenomenon is based on spatial autocorrelation by virtue of the nature of the observed phenomenon of being continuous in space (Majumdar & Biswas, 2016) (Fig. 3), while the administrative divisions represent, obviously, a discrete partitioning. The flow diagram of the proposed methodology highlights the framework and main references.



Step	Phenomenon Temperature variation	Spatial dimension	References
01	Observation	Labor Market Area (LMA) and Metropolitan city (MC)	Majumdar, D. D. & Biswas, A. (2016)
02	Representation of the phenomenon	Spatial autocorrelation (LISA)	Yang, L.,et al (2021)
03	Policy targets	Metropolitan city (MC)	Hurlimann, A., Moosavi, S., & Browne, G. R. (2021)

Fig.3 The flow diagram of the proposed methodology

The temperature, referring to spatial units that are generally contiguous in geographical terms, can benefit from a vast set of spatial analytical techniques to evaluate their local and proximity effects. In such a sense, evaluating the so-called spatial autocorrelation of data or indicator to a set of contiguous geographical units, can be useful for evaluating local effects and clusters in terms of attribute and geographical data. Area units in fact can mutually influence themselves in geographical terms and in terms of the data referred to such units. In geographic analytical terms, Tobler has highlighted (Tobler, 1970) as "nearby things are more related than distant things", apparently an intuitive approach (Tobler, 2004), although only recently rediscovered (Sui, 2004). Spatial autocorrelation is a tool that allows you to observe the behavior of a variable with respect to its

[1] https://www.ipcc.ch/report/ar6/wg2/

position in space and with respect to what occurs in its proximity. Through two categories of information such as location and related properties it is possible to describe geographic objects. In particular, in analytical terms, spatial autocorrelation can be defined as follows (Lee et al., 2000):

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

Where:

- i and j are two objects or events in space;
- N is the number of objects or events;
- c_{ij} is a degree of similarity of attributes i and j;
- w_{ij} is a degree of similarity of location i and j; From the general formula two indices derive as the Geary C Ratio (Geary, 1954) and the Moran Index I (Moran, 1948).

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:

$$c = \frac{(N-1)(\sum_i \sum_j w_{ij}(x_i - x_j)^2)}{2(\sum_i \sum_j w_{ii}) \sum_i (x_i - \underline{x})^2} \quad (2)$$

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

$$I = \frac{N \sum_i \sum_j w_{ij}(x_i - \underline{x})(x_j - \underline{x})}{\sum_i \sum_j w_{ij}(x_i - \underline{x})^2} \quad (3)$$

As recalled and applied recently in several Italian contexts (Murgante et al., 2012), these indices are quite similar, differing by the cross-product term in the numerator, calculated using the deviations from the mean in Moran, while directly computed in Geary. The main message coming from the indices is highlighting the presence - or absence - of spatial autocorrelation at a global level in the overall distribution, while the local presence of autocorrelation can be highlighted by the LISA (Local Indicators of Spatial Association), or, as after Anselin (Anselin, 1988; Anselin,1995), a local Moran index, as the sum of all local indices is proportional to the value of the Moran one:

$$\sum_i I_i = \gamma * I \quad (4)$$

The index is calculated as follows:

$$I_i = \frac{(X_i - \underline{X})}{S_X^2} \sum_{j=1}^{N} (w_{ij}(X_j - \underline{X})) \quad (5)$$

The index allows assessing for each location assess the similarity of each observation with its neighbors, and five combinations can be obtained from its application:

- hot spots: areas with high values of the phenomenon and a high level of similarity with its surroundings (high-high H-H);
- cold spots, as areas with low values of the phenomenon and a low level of similarity with its surroundings (low-low L-L);
- potentially spatial outliers, with high values of the phenomenon and a low level of similarity with its surroundings (high-low H-L);
- potentially spatial outliers, with low values of the phenomenon and a high level of similarity with its surroundings (low-high L-H);

- lack of significant autocorrelation. The interesting characteristic of LISA is in providing an effective measure of the degree of relative spatial association between each territorial unit and its neighboring elements, thereby highlighting the type of spatial concentration and clustering.

An important element to be considered in the above-mentioned equations, related. The neighborhood property is analyzed by means of the parameter weight, w_{ij}, whose values indicate 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 cases in which i and j are not neighbors, or 1 when i and j are neighbors. Neighborhood is computed in terms of contiguity such as, in the case of areal units, sharing a common border of non-zero length (O'Sullivan & Unwin, 2010).

3. Case study of Cagliari: Metropolitan City (MC) and Labour Market Area (LMA), Sardinia, Italy

As a study area, the metropolitan city of Cagliari was chosen to test the methodology and as a testbed for another, wider study to be extended to the national territory, other than to an international context. Such a choice was justified, from the Italian administrative subdivisions point of view, by the presence of a Metropolitan City in Sardinia region built more on functional terms rather than on administrative ones, which generally happens in most of the other Italian Metropolitan City. In the Italian case, the recent laws re-defining the intermediate administrative levels - as those lying between Regions and Municipalities, has led to defining Metropolitan Cities, together with Provinces and other inter-municipal aggregations, starting generally from the previous organization of Municipalities in provinces, or in any case following more an administrative aggregation rather than focusing on a functional or systemic aggregation of lower-level administrative units. The study area is therefore represented by the metropolitan city of Cagliari, both in its administrative (MC) and statistical functional meanings as represented by the LMA as identified by Italian National Institute of Statistics (ISTAT). It is known that defining urban and metropolitan areas is not an easy task and simulations and proposals were done at national and international level (i.e., see the EU proposals for the Functional Urban Areas - FUA). However, LMA can be used for a functional exam of the working / studying - related movements to and from a major pole in a given area. Their extension can therefore be considered as the gravitation area of a city. In the case of Cagliari, we can recall it as the major city of Sardinia Region. The city of Cagliari is the capital of the Sardinia Region and Metropolitan City since 2016, and is the most important cultural, economic, political and administrative center of Sardinia. It is a new administrative structure of 17 municipalities. The Municipality of Cagliari hosts over 150,000 inhabitants, while the Metropolitan City spans nearly 420,000 inhabitants (ISTAT, 2022). Cagliari is the most important cultural, economic, political and administrative center of Sardinia. It plays a role as the major urban area in the Island (Table 1).

Cagliari	Population (2022)	Mr. of Municipalities
Municipality	148,881	1
Metropolitan City – MC	419,770	17
Labour Market Area – LMA	500,398	42
Cagliari + South Sardegna	754,878	124

Tab.1 Cagliari, summary demographic statistics. Source: our elaboration on data from ISTAT (2022)

The idea of addressing the topic considering two different aggregations of municipalities gravitating around a major, capital one, is that of putting together the administrative level where appropriate environmental policies can be put in action, and a wider area where such actions could be effective, given the continuity in space of climate-related phenomenon aimed at climate neutrality. We considered the MC as the administrative and political context in which policies and actions and also the broader belt of municipalities surrounding the Metropolitan city, an extended buffer zone whose area can be considered as that of LMA. On one side, in fact, there was the need to limit the edge effect when performing the LISA – Local Moran compilation. As the algorithm considers neighboring area units, limiting the analysis to the sole municipalities belonging to the MC would have caused the information to be distorted at extreme edges of its external border. Therefore, a second belt of Municipalities around the major one – the municipality of Cagliari – would be an option to consider, in order to smooth and limit the edge effect. Another motivation lies in the functional aggregation of municipalities of the area related to the functional aggregations of the area in terms of commuting. The above-mentioned LMA are in fact based on self-containment in terms of such set of movements and therefore can provide a flavor of the gravitation powers in given municipalities, in particular if they host a MC.

4. Results

The analysis was performed considering the average yearly temperature registered over a wide timeframe, from 1960 to 2018, attributed to each Municipality (MC and LMA of Cagliari, Sardinia, Italy). Such data were used as the input for the computation of LISA and in particular the local Moran's I. The analysis was performed on the temperature data in 1960 and 2018. Also, the computation was run onto the temperature difference between the initial and final periods. The results are displayed in figures 4, 5, 6 and 7 (LISA Significance Map and Moran's I Scatterplot). As mentioned above, Moran's I is aimed at clustering areas in terms of similarity in a selected attribute together with a spatial contiguity.

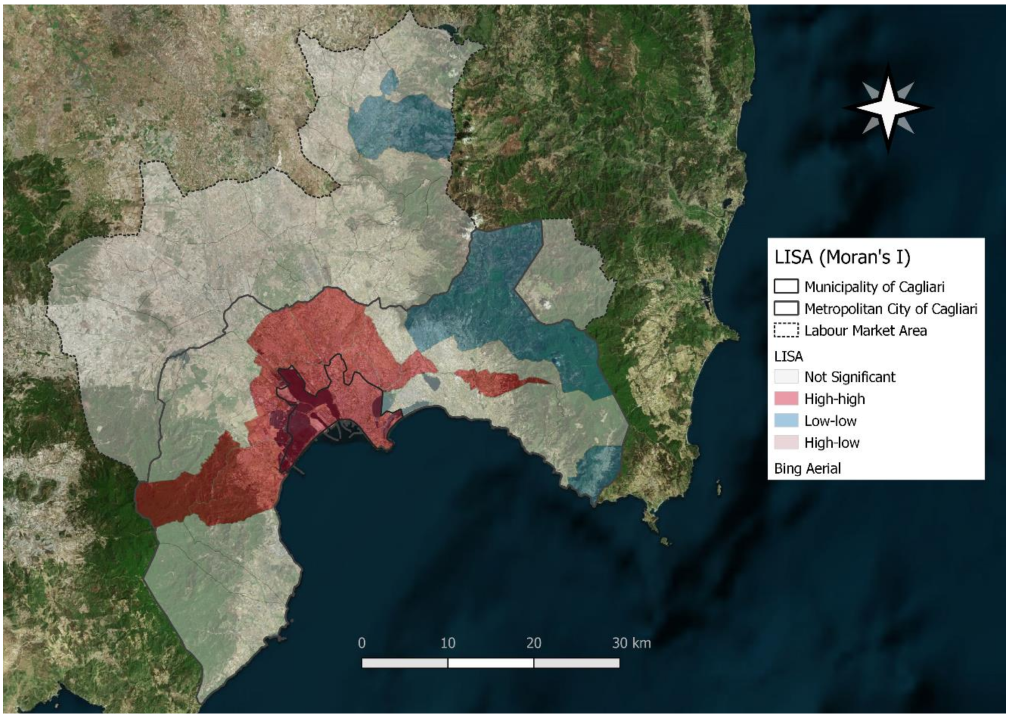


Fig.4 Lisa Map: Temperature 1960. Cagliari: MC and LMA

The analysis performed on 1960 data presents a situation of clustering – hi-hi autocorrelation – of the municipalities in the first belt around the municipality of Cagliari - with the exception of the Municipality of Quartu Sant'Elena, East from Cagliari.

The other municipalities of both the to-date LMA and MC are not significant in terms of spatial autocorrelation, or assume low-low autocorrelation - Municipality of Sinnai, Eastern limit of to-date MC.

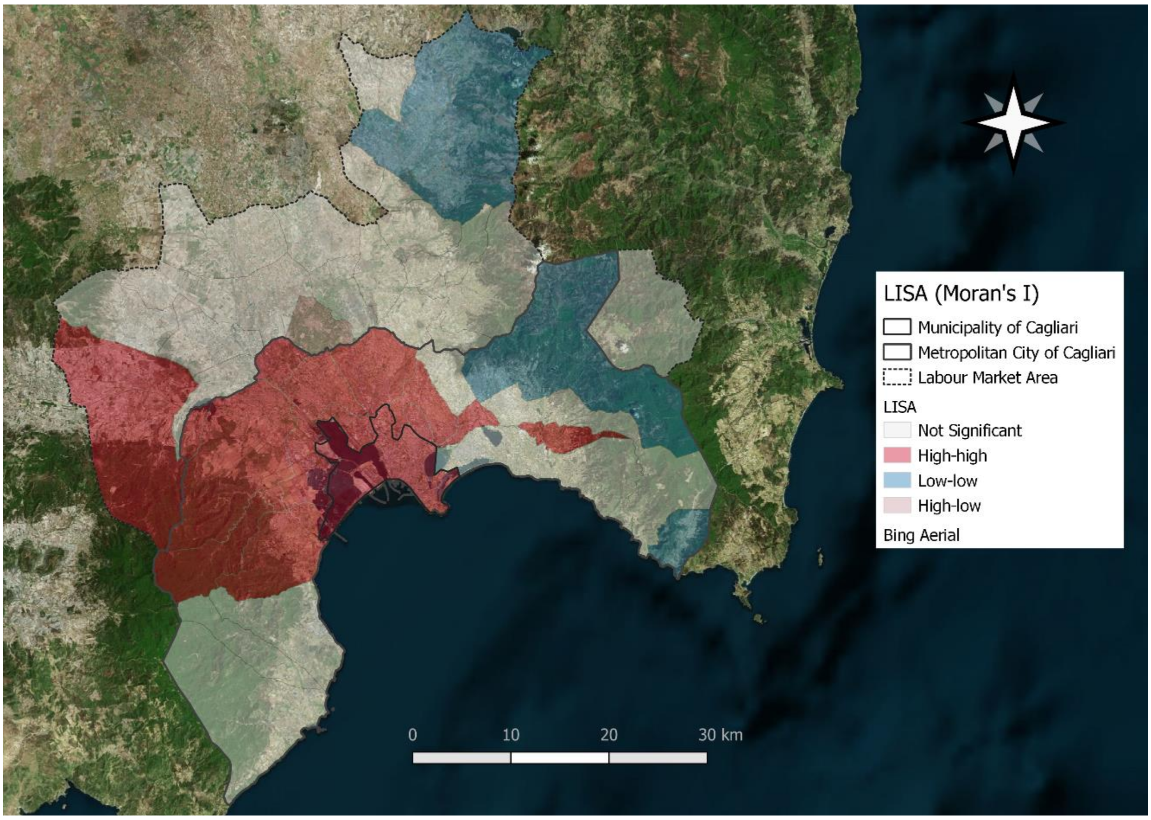


Fig.5 Lisa Map: Temperature 2018, Cagliari: MC and LMA

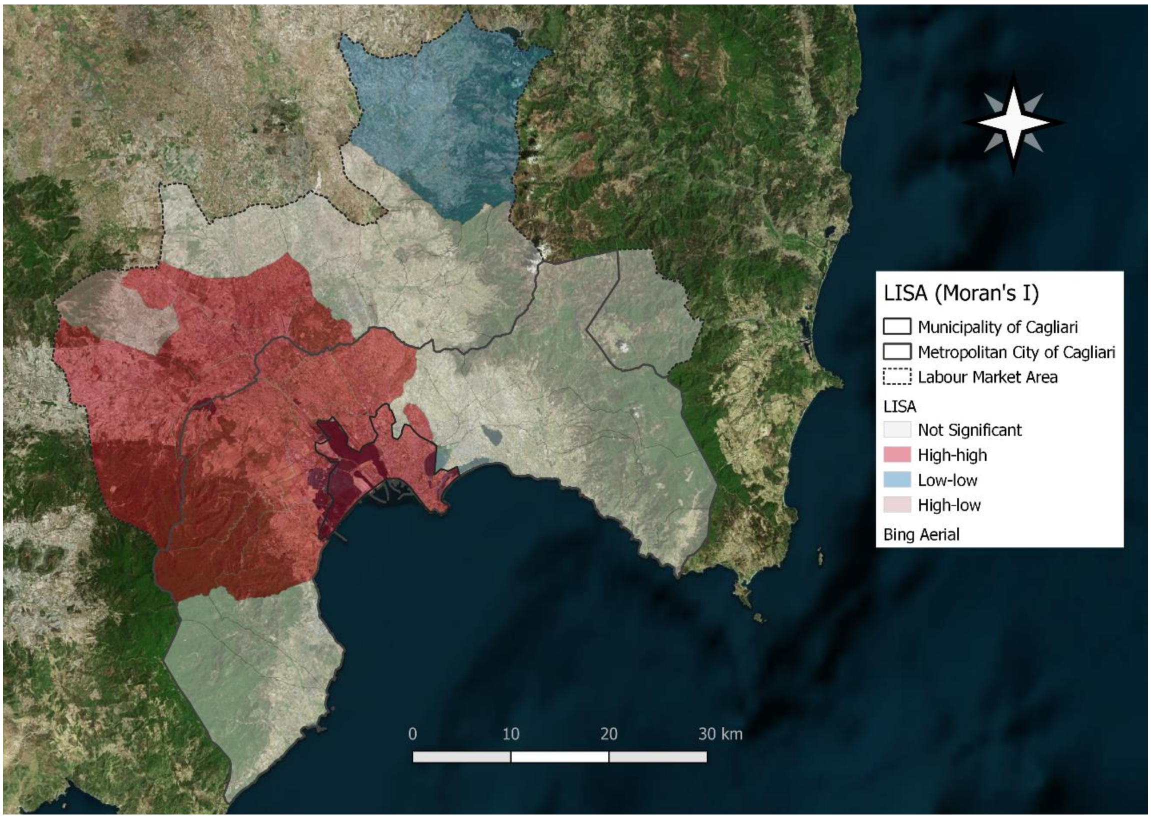


Fig.6 Lisa Map: Temperature delta (1960-2018) Cagliari: MC and LMA

The analysis on 2018 data shows an average increase of 2.7 Celsius degrees in the MC of Cagliari – 2.8 if we consider the average value of the municipalities belonging to Cagliari LMA – and high values of spatial autocorrelation as explored by the Moran's I can be found in the same municipalities as observed in 1960, extended to include those belonging to the second belt around the city of Cagliari and oriented towards the Northwestern part of the area considered. A further analysis was performed considering the absolute variations in temperature as registered from 1960 to 2018. It is worth noting that the major changes occurred particularly from the end of the '90s of the past century and the first two decades of the XXI century, however an analysis on the overall changes was performed as well using local Moran's I. The analysis on the overall changes occurred confirms the pattern as drawn in the 2018 exam, with a wide set of Municipalities belonging to the MC and the LMA of Cagliari clustered, following particularly a South-East – North-West orientation, centered on the Capital Municipality of Cagliari.

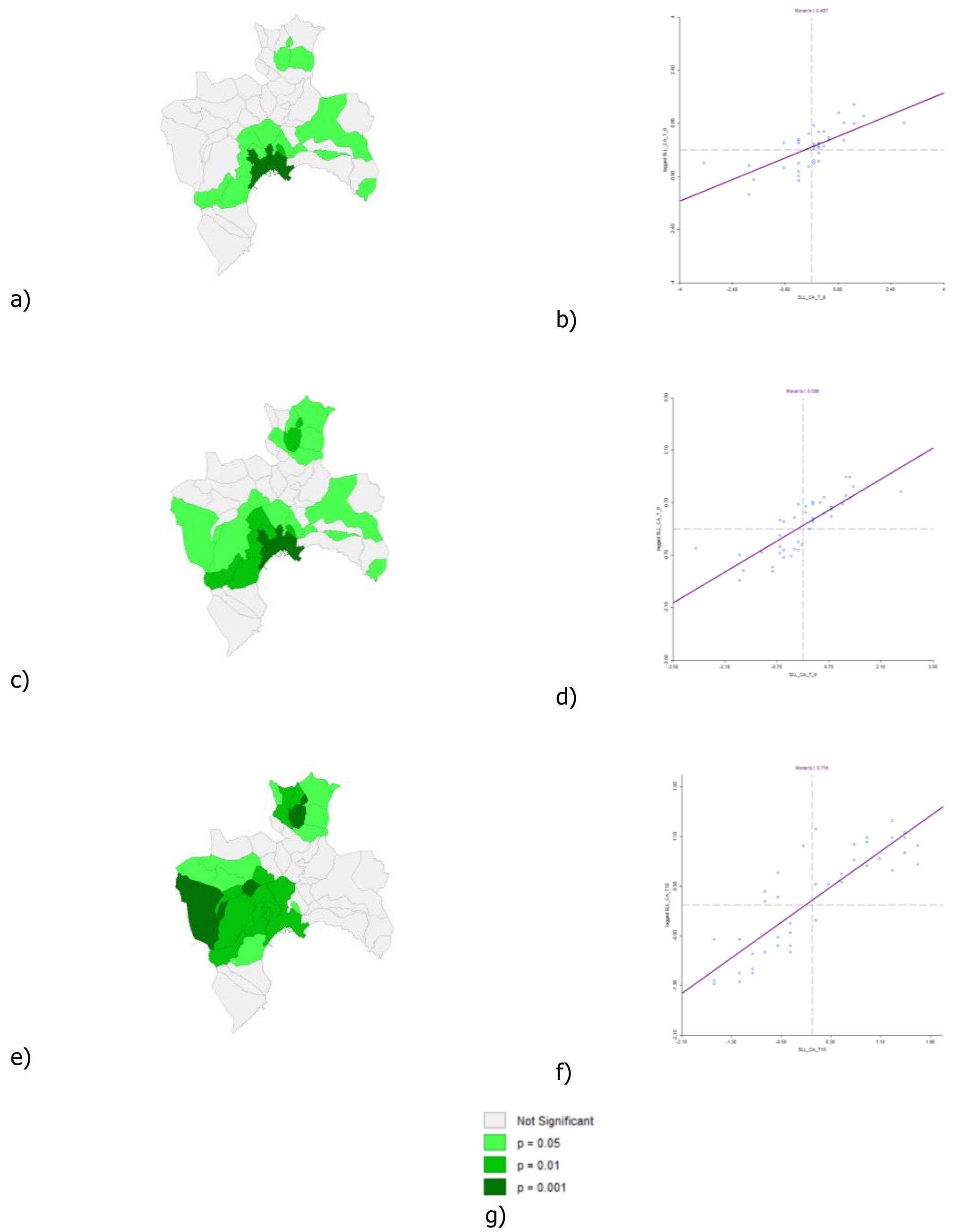


Fig.7 LISA Significance Map and Moran's I Scatterplot. Significance maps years 1960 (a), 2018 (c), difference 2018 - 1960 (e); Legend of Significance Maps (g). Moran's I scatterplots 1960 (b), 2018 (f), difference 2018 - 1960 (f)

From this first methodological application makes evident, once more, the existing mismatch, at least in the Italian administrative system, among the functional and administrative dimension. Italy for statistical purposes has identified the Labor market area (LMA) as aggregations of municipalities clustered in terms of their gravitation around certain locations presenting an attractive power to other external settlements. Such an instrument is of particular use for determining areas of gravitation for industrial and service activities, and, as a peculiarity of the Italian industrial system, for determining the areas where industrial districts could be detected. Their shape and extension is constantly monitored and updated as soon as commuting flows and population data are updated. However, they are not used from an administrative point of view but as statistical reference. Italy passed through several redesign and shaping of the intermediate administrative level, those lying between that of the Municipalities, and the Regions, these latter holding a particular authority in policies on spatial planning, transport and health, just to mention a few. Italian Provinces were reformed in 2015, and that led to the institution of the Metropolitan Cities (MC), as originally foreseen already during the Nineties of the past century. Their design, however, followed particularly an administrative path, not necessarily related to functional and/or systemic approaches in designing service areas around nodal cities. The administrative concept of ‘Metropolitan City’ in the Italian system is therefore different to that of a proper ‘Metropolitan Area’ or, as in the European nomenclature, Functional Urban Area.

5. Discussion

In the present manuscript, the combination of the two different spatial concepts (LMA and MC) related to the city of Cagliari allowed on one side to observe a phenomenon, that related to the temperature as representative of climate changes, in a context of proximity of relation – as the Labour Market Area (LMA) ones, in terms of industry, service, agricultural production, transport infrastructure, etc. – spanning out from administrative borders and therefore capable of maintaining a robust analysis of the variability of the phenomenon; on the other side, it allowed to understand to what extent the current administrative pattern is both non completely valid to detect phenomena that have consequences on its territory, although generated outside it, and, from another point of view, the MC is necessarily involved and asked to intervene for proposing climate neutrality policies. The cluster characterized by the increase in temperature, are those characterized by a more flat morphology – built and / or used for production activities, traditionally oriented towards the northwest from Cagliari (towards the main road transport infrastructure of Sardinia).

The results of this first methodological application show how the administrative territorial dimension of the metropolitan city is not representative for the observation of the phenomenon related to the change in temperatures. Furthermore, this methodology allows to highlight the municipalities and therefore the potentially vulnerable community deriving from thermal change. Some summary statistics derived from the analysis carried on, show as the cluster of municipalities where the major temperature increase occurred in the most recent period host a percentage close to 20 of the vulnerable resident population (over 65 years), counting around 77 thousand people in the Metropolitan City (touching 420 thousand people in 2022), what involves taking a series of urgent actions within the Metropolitan Urban Planning Plan, with the aim of mitigating and adapting the climatic effects. Actions are no longer negligible as, in fact, the increase in temperature in metropolitan city of Cagliari, but also in all Italian metropolitan cities is accompanied by the progressive aging of the population and therefore by the progressive increase in the vulnerability of the urban communities.

The research carried on and presented in the current manuscript represents a local demonstration of the need to consider the different spatial units of analysis and policy related to a country - or, considering a wider, international scenario, a set of countries as the European ones could be. As it often happens, the phenomena needing to be addressed are continuous in space - such as a rise in temperature and/or, more in general, the issues related to climate change. However, the decision making process is generally tackled considering discrete partitioning of space, often non-optimal in their pattern and extension, and little flexible in terms of adaptability of changes. The recent restructuring of the Italian intermediate set of administrative units - that including Provinces and Metropolitan Cities - confirmed in most of the cases shapes and extensions of areas conformed to a well rooted system, with little changes occurring. An exception, as mentioned, is that of the Metropolitan City of Cagliari, whose extension is different from any other administrative partition adopted in the past. Nonetheless, given the increase in the importance of the city at regional level, its catchment area or hinterland is wider and needs to be addressed at a wider spatial scale, at least from the analytical point of view. Italian Labour Market Areas are such that they are updated regularly, according to the changes intervening in the commuting and residential habits of people and, particularly in the past, were fundamental in highlighting Industrial Districts, as the backbone of Italian Small and Medium Enterprise system that characterized particularly the last decades of the past century. The occasion, therefore, was that of reflecting on the need to consider different spatial units and analytical tools to couple analysis and policy proposals at spatial level.

6. Conclusions and future development

During the twentieth century, the world has increased tenfold both the use of fossil fuels and the extraction of natural resources. This seemingly rich era of abundant and cheap resources is drawing to a close. Raw materials, water, air, biodiversity and marine, terrestrial and aquatic ecosystems are all under pressure from thermal change. There is a need to monitor the variations occurring in temperature in the different contexts, particularly those characterized as urban and periurban, where industrial, services and residential activities developed with particular evidence in the latest years. Also, there is the need to overcome the administrative organization of territories for studying phenomena, coordinating actions in order to allow administrations to intervene on their own territories, without forgetting the effects actions and policies can have on neighboring areas. In the particular case, the analysis portrayed the situation of the temperature increase in two major aggregations, as the Metropolitan City and the Local Market Area of Cagliari. Clustering of municipalities with increased temperature in the years popped up, allowing also to estimate figures of population at risk due to the changes intervened.

Such an analysis allowed, other than to observe the changes occurred in time and space in terms of the phenomenon observed, to highlight the need to focus on different levels of spatial aggregations when dealing with the political action’s level of one side - the more rigid administrative level of the official spatial units - and the effect on the true territorial extension of the phenomenon on one side, and of the metropolitan context on the other one.

Future research direction will involve considering the Italian Metropolitan Cities and their related Local Market Areas, therefore extending the analysis to the entire country, to observe the behavior of the phenomenon in time and space, not just limited to a single case or part of a region. The idea is also that of considering other ‘shapes’ and extensions of the metropolitan areas, as those proposed at European level of the FUA – Functional Urban Areas, realized by a composite indicator of commuting, residential density and availability of services. This will allow considering a third level of aggregation, in continuous update based on Earth’s observation technology (Copernicus project, based on remotely sensed satellite data). Particular attention will be paid to the vulnerability analysis of the population (age and spatial distribution). Finally, the climate mitigation policies of metropolitan cities will be assessed to determine coherence with the recorded climate changes.

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Image Sources

Fig.1: Ginevra Balletto, 2022;

Fig.2: Authors' elaboration from ISTAT base data, 2022;

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