Minimum Environmental Criteria and Climate Issue in the Metropolitan Urban Ecosystem

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Abstract. In Italy, the adoption of the Minimum Environmental Criteria (MEC) is associated with Legislative Decree 50/2016, which regulates public tenders. The main objective of the MECs is to promote the purchase of sustainable goods and services thus contributing to the reduction of the environmental impact and the protection of natural resources. Furthermore, the adoption of MEC by public authorities represents a strategic choice to promote the circular economy, reduce waste and greenhouse gas emissions, thus preserving the quality of environmental matrices. MECs, although they are innovative tools, are however lacking in geographic information related to context analysis. In this synthetic framework, the objective of this work is to evaluate a set of contextual environmental indicators to support the MECs. In fact, the knowledge and representation of the context constitutes a fundamental action for recognizing local problems, which are also useful for understanding global issues. Furthermore, how can MECs contribute to adaptation to climate change within the relative territorial context? This question guided the manuscript and the metropolitan city of Cagliari represents the case study.

Keywords: Minimum Environmental Criteria · Climate Issue · Metropolitan City

1 Introduction

The problem of climate change, is the subject of a complex scientific debate and international commitments aimed at reducing climate-altering greenhouse gas emissions [1]. The increase in average temperatures, the frequency of extreme meteorological events such as intense rainfall, heat waves and droughts, constitute the main phenomena of climate change and are closely related to the geographical conditions of the contexts [2].

Climatic variations also have significant impacts on cities as, as a matter of example, increase in temperature, heavy rains and consequent flood risks and other water-related problems, such as the risk of coastal erosion and the risk of drought [3, 4]. Furthermore, in

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cities the combination of the increase in the average annual temperature with the urban heat island effect [5] can amplify climate change, resulting in an increased demand for energy for cooling buildings and infrastructure, whose gas emissions contribute to altering the climate, contributing to the consolidation of the climate-city relationship [6]. Climate adaptation and mitigation strategies in cities are therefore urgently needed, including the reduction of greenhouse gas emissions, the sustainable electricity transition and the promotion of sustainable behavior among citizens, businesses and public administrations [7, 8]. In this sense, the MECs constitute a set of rules and standards that the public administration must respect in order to reduce the environmental impact in the provision of its services. The MECs were introduced to promote the adoption of eco-sustainable behaviors and can concern various aspects, such as the reduction of the environmental impact of production processes, the use of recyclable or biodegradable materials, the reduction of energy consumption, the use of renewable energy sources, the reduction of polluting emissions and water consumption, the management of waste produced during production and distribution and more. The main objective of MEC for public administration is to reduce the environmental impact of services, promoting the adoption of more sustainable technologies and production processes and reducing the overall environmental impact of production and consumption [9]. MECs was born in the 80s, when international governments and then the EU began to recognize the importance of reducing the environmental impact of production and commercial activities. In the following years, MECs have been adopted by many other international organizations, national governments, regional and local authorities, as well as non-governmental organizations [10]. MECs are an important tool to promote environmental sustainability, also contributing to the transition towards a greener and more sustainable economy. However, the MECs have some limitations: they can be interpreted as a minimum and not a maximum requirement, therefore adherence to these criteria may not guarantee maximum environmental sustainability; finally, the application of MECs can be difficult to monitor in the territorial context of reference, also because the context does not constitute a relevant field of investigation.

In this framework, the aim of the paper is to investigate to identify a set of functional environmental indicators to represent the municipal territorial context, within which the urban projects that adhere to the MECs can be monitored in relation to the local sustainable development challenges [11, 12].

The paper is organized as it follows: Sect. 2 Material and Method; Sect. 2.1 Temperatures and human factors; Sect. 2.2 Metropolitan City (MC) and Functional Urban Areas (FUA); Sect. 2.3 Methodology; Sect. 2.4 Data; Sect. 3 Case study; Sect. 4 Results and Discussion and Sect. 5 Conclusions and future development.

2 Material and Method

Luke Howard [13] through the study of the relationships that regulate the relationship between climate and city, managed to systematize about 30 years of observations of this dual relationship. In addition to the influence of large-scale meteorological phenomena, it was the city with its own structure and distribution that significantly influenced the local climate by intervening on the flow of air currents, on the distribution of humidity and on the temperature regime, differentiating the environmental parameters of the cities and nearby areas. However, the scientific debate only became animated in the late 80s and early 90s and since then research, models and methods have been proposed to monitor and/or contrast the change that can also be associated with the progressive phenomenon of metropolisation [14], which requires climatology associated with urban planning and tools to govern the processes of climate-city interaction. In this sense, a set of indicators was selected - sentinel indicators - able to represent the climate_city interaction associated with the territorial dimension of the metropolitan city: land take [15]; green area [16]; sustainable energy [17] and greenhouse gas emission [18] in order to monitor-govern the complex climate-city interaction (Fig. 1).

CRITERIA	INDICATORS	SOURCE
1. Land take	1.1 Airports 1.2 Continuous urban fabric (S.L. : > 80%) 1.3 Discontinuous low density urban fabric (S.L. : 10% – 30%) 1.4 Discontinuous medium density urban fabric (S.L. : 30% – 50%) 1.5 Discontinuous very low density urban fabric (S.L. : < 10%) 1.6 Industrial, commercial, public, military and private units 1.7 Isolated structures 1.8 Land without current use 1.9 Roads, port areas, railways and associated land 1.10 Sports and leisure facilities 1.11 Water	Urban Atlas https://bit.ly/2Kq8Frz
2. Green Areas	2.1 Forests 2.2 Green urban areas	Urban Atlas https://bit.ly/2Kq8Frz
3. Sustainable energy	3.1 Bioenergy 3.2 Eolic 3.3 Photovoltaic 3.2 Hydroelectric	Terna S.p.a. https://bit.ly/3Zc7L7G
4. Greenhouse gas emission	4.1 CO2 emissions	ISTAT https://bit.ly/3K6NQCG

Fig. 1. Set of indicators to represent the climate_city interaction in the territorial dimension of the metropolitan city (Authors: Balletto G. and Sinatra M., 2023)

2.1 Temperatures and Human Factors

New complex challenges between local and global emerge. Identifying strategies to contain environmental impacts, the consumption of resources within a growing and gradually aging international demographic framework represents a shared priority within the scientific debate. Furthermore, the trend of metropolisation [19] of the last decades is bound to go on. It is estimated that the population in 2050 will be approximately 70% urban, which requires urgent sustainable planning strategies. The city, as a spatial organization with a high anthropic concentration: residential, production/services and mobility, as well as being the generator and recipient of numerous and complex environmental impacts, is also subject to significant thermal variations, called heat islands. Forecasts over a period of about forty years show worrying scenarios with an increase in global temperature of 2 to 4 °C, and with greater increases precisely in urban areas [20–22] and heavy consequences on the balance of natural ecosystems. In Italy, inparticular, the average temperature of the period 2009–2018 exceeded that of the years 1961–1970 by more than 2°C. This increase is worrying both in terms of intensity and frequency and for the exposure of communities, in particular for sensitive ones (over 65 - currently growing), as well as for the progressive vulnerability extended to buildings, roads, monuments [23, 24].

2.2 Metropolitan City (MC) and Functional Urban Areas (FUA)

Metropolitan Cities were established in Italy in 2014, with the primary task of promoting socio-economic development and contributing to the competitiveness and growth of the national economy. The metropolitan cities represent the intermediate administrative dimension between the municipal and the regional one, based on the population density, whose trend over time has been increasing towards the peripheral municipalities. In fact, the Italian metropolitan cities have been affected by significant demographic phenomena, first of growth and then of decline, so much so that by 2030 they are expected to be characterized by a significant demographic decline with important socio-economic consequences [25].

The administrative dimension of metropolitan cities derives, however, from a previous definition, that of the FUA -Functional urban area- developed by the OECD in 2004 based on population density to identify urban cores and home-work travel flows to identify the hinterland, or where the labor market is highly dependent on the main urban centres [26]. In particular, by FUA we mean a spatially continuous urban settlement made up of several administrative units. The OCSE methodology makes it possible to compare functional urban areas of similar size, located in various European countries, according to the following classification:

- Small urban areas, with a population $>$50,000 and $<$200,000;
- Medium urban areas, with population $>$200,000 and $<$500,000;
- Metropolitan areas, with populations $>$500,000 and $<$1.5 million;
- Large metropolitan areas, with population $>$1.5 million.

Europe is made up of a polycentric network of urban areas in which the FUAs defined by the OCSE although the FUAs constitute only a part of its urban structure, nevertheless identify the relationships with the peri-urban areas, in analogy to the "Local systems of the work" defined by ISTAT, on the basis of the "daily commute to work". The metropolitan city therefore represents the administrative dimension for governance, while the FUA represents a compatible dimension for analysis, because it better represents the spatial organization and urban relations such as commuting [27].

2.3 Methodology

The proposed method consists in identifying a set of indicators able to represent the following variations of the phenomena: temperature, soil consumption, green areas, sustainable energy production and greenhouse gas emissions (CO_2) [28, 29]. In particular, the temperature variation was represented by spatial autocorrelation, thus highlighting the positive proximity relationships. All the other indicators, on the other hand, were represented by spatial distribution (Fig. 2).

ID	PHENOMENONS	SPATIAL DIMENSION	LITERATURE
1	Temperature variation	Municipality/ Metropolitan City	Yang et al. (2021)
Representation of the phenomenon		Spatial autocorrelation LISA	Balletto et al. (2022)
2	2.1 Land take; 2.2 Green areas; 2.3 Sustainable energy; 2.4 Greenhouse gas emission	Municipality/ Metropolitan City/ Regional	Moldan et al. (2007) Verma et al (2018)
Representation of the phenomenon		Spatial distribution	

Fig. 2. Climate_city interaction: Set of indicators and territorial dimension (Authors: Balletto G. and Sinatra M., 2023)

LISA Method

Local Indicators of Spatial Autocorrelation (LISA) were considered useful for examining the phenomenon under observation and, particularly, to analyze the behavior of certain data and variable in the geographical space, taking into consideration the characteristic of geographical feature of autocorrelate in space. Area units in fact can mutually influence each other in geographical terms and in terms of the data referred to such units. In geographic analytical terms, Tobler in his 'First Law of Geography' highlighted [30] as "nearby things are more related than distant things", an intuitive approach [31] recently rediscovered [32], that allows, by means of the appropriate tools for its analysis, to observe the behavior of a variable related to its position in space and with reference to its proximal units. 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 [33]:

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

where:

- i and j are two objects or events in space;
- N is the number of objects or events;
- cij is a degree of similarity of attributes i and j;
- wij is a degree of similarity of location i and j.

From the general formula two indices derive as the Geary C Ratio [34] and the Moran Index I [35]. Defining xi as the value of object i attribute; if $c_{ij} = (x_i - x_j)^2$, Geary C Ratio can be defined as follows:

$$C = \frac{(N-1)\left(\sum_i \sum_j w_{ij}(x_i - x_j)^2\right)}{2\left(\sum_i \sum_j w_{ij}\right)\sum_i (x_i - \underline{x})^2} \tag{2}$$

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

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

Geary and Moran indexes, as recalled and applied in several Italian contexts [36], are similar in their overall meaning and message, 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 [37, 38], a local Moran index, as the sum of all local indices is proportional to the value of the Moran one:

$$\sum_i I_i = \gamma * I \tag{4}$$

The index is calculated as follows:

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

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.

The neighborhood property is based on weights, seen particularly as indicators of contiguity eights, w_{ij}, indicate the presence, or absence, of neighboring spatial units to a given one. A spatial weight matrix is needed, 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 [39].

2.4 Data

The current global warming can be quantified with an increase in average temperatures of over 2 °C in the last 50 years. Among the numerous studies on the climate issue, the Glocal Climate Change (2020) [40] carried out by OBC Transeuropa for the European Data Journalism Network (EDJNet) was selected and focuses on the increase in average temperatures in Europe. The EDJNet reference data were retrieved from the "UERRA regional reanalysis for Europe on single levels from 1961 to 2018", a dataset created by the Copernicus initiative and the European Center for medium-range weather forecasts, containing estimates of the temperature measured at two meters above the ground with reference to a grid composed of cells of 5.5 × 5.5 km.

To evaluate the thermal variation, the value of the annual average temperature was calculated, referring to the two time intervals 1961–1970 and 2009–2018, for each cell. Subsequently, a European municipality was assigned to each of the latter, taking into consideration urban density and the conformation of the coast. Figure 3 shows the temperature values for the Metropolitan City of Cagliari, interval 2006–2018, with the relative absolute variation.

According to the literature review (Sect. 2), a dataset is proposed, as summarised in (Table 1).

Municipality	Assemini	Cagliari	Capoterra	Decimomannu	Elmas	Maracalagonis	Monserrato	Pula	Quartu Sant'Elena	Quartucciu	Sarroch	Selargius	Sestu	Settimo San Pietro	Sinnai	Uta	Villa San Pietro
Temperature 2006 [C°]	17.5	19.3	18.2	17.4	18.0	16.9	18.1	16.6	17.9	17.3	17.4	18.1	17.3	16.6	16.6	17.3	16.6
Temperature 2018 [C°]	17.6	19.2	17.9	17.3	17.7	16.3	17.8	15.9	16.8	16.8	16.8	17.8	17.0	16.0	16.0	17.1	15.9
Temperature variation [C°]	+ 0.1	- 0.1	- 0.3	- 0.1	- 0.3	- 0.6	- 0.3	- 0.7	- 0.5	- 0.5	- 0.6	- 0.3	- 0.3	- 0.6	- 0.6	- 0.2	- 0.7

Fig. 3. Temperatures of the metropolitan city of Cagliari (2006–2018) - EDJNet. Source: https://climatechange.europeandatajournalism.eu/it/

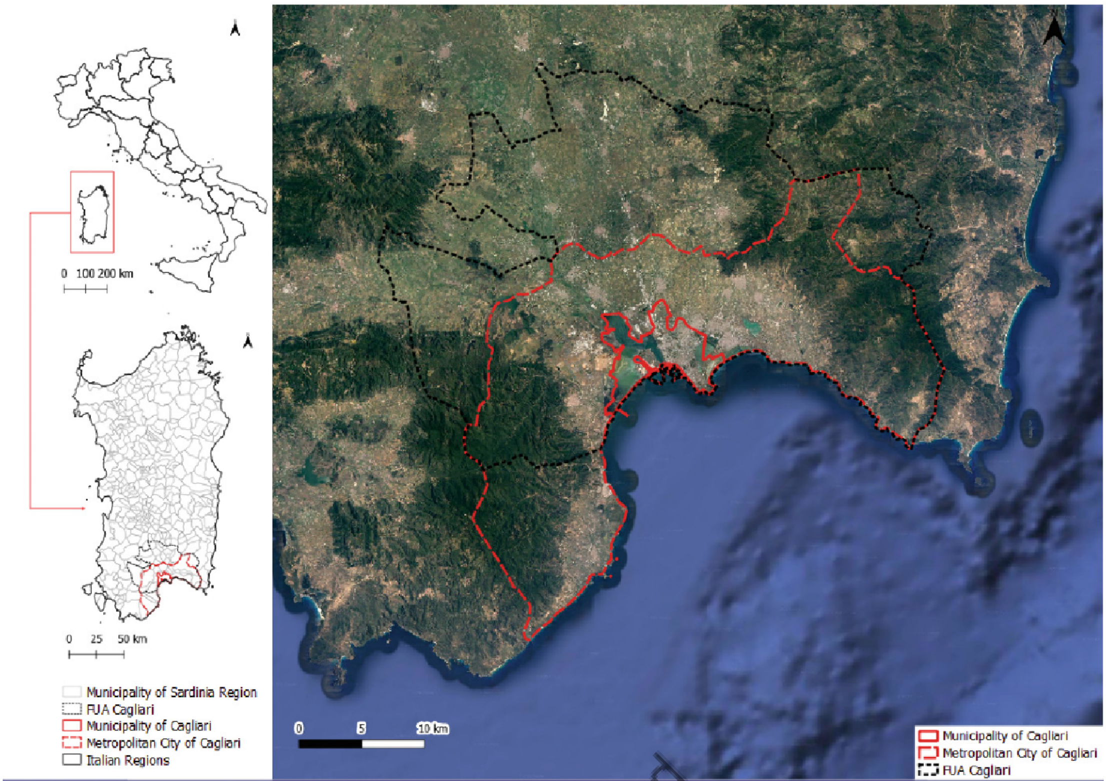
Table 1. Climate city interaction indicators (Authors: Balletto G. and Sinatra M., 2023).

ID	Criteria	Indicators	Source
01	Land take	FUA land-use classes	Urban Atlas (2006–2018)
02	Green Areas		
03	Sustainable energy production	Efficient power for renewable sources	Terna S.p.a. (2006–2018)
04	Greenhouse gas	CO_2	ISTAT (2006–2018)

Sources: Urban Atlas - https://bit.ly/2Kq8Frz; Terna S.p.A. - https://bit.ly/3Zc7L7G; Istat - https://bit.ly/3K6NQCG

3 Case Study

As a study area to test the methodology, the metropolitan city of Cagliari was chosen, because it is also of regional importance. It is an administrative intermediate unit established in Sardinia by the regional law n. 2 of 2016 and became fully operational on 1 January 2017. It consists of 17 municipalities and has a population of 420,000 inhabitants [41]. The city of Cagliari is the capital of the Autonomous Region of Sardinia and of the metropolitan city and is the economic, political and administrative center of Sardinia (Fig. 4).



CAGLIARI	POPULATION (2022)	NO. OF MUNICIPALITIES
Municipality	148 881	1
Metropolitan City (MC)	419 770	17
Functional Urban Areas (FUA)	486 106	32
Cagliari + South Sardinia	754 878	124

Fig. 4. Study area and its population (Authors: Balletto G. and Sinatra M., 2023).

4 Result and Discussion

The analysis was carried out considering the average annual temperature recorded over a time interval, from 2006 to 2018, attributed to each municipality of the metropolitan city of Cagliari. These data were then used as input, in particular, for the local Moran's I calculation and the related LISA map. The analysis was conducted on the temperatures of 2006 and 2018.

The results are reported in Fig. 5, Fig. 6 and Fig. 7 (LISA Significance Map and Moran's I Scatterplot).

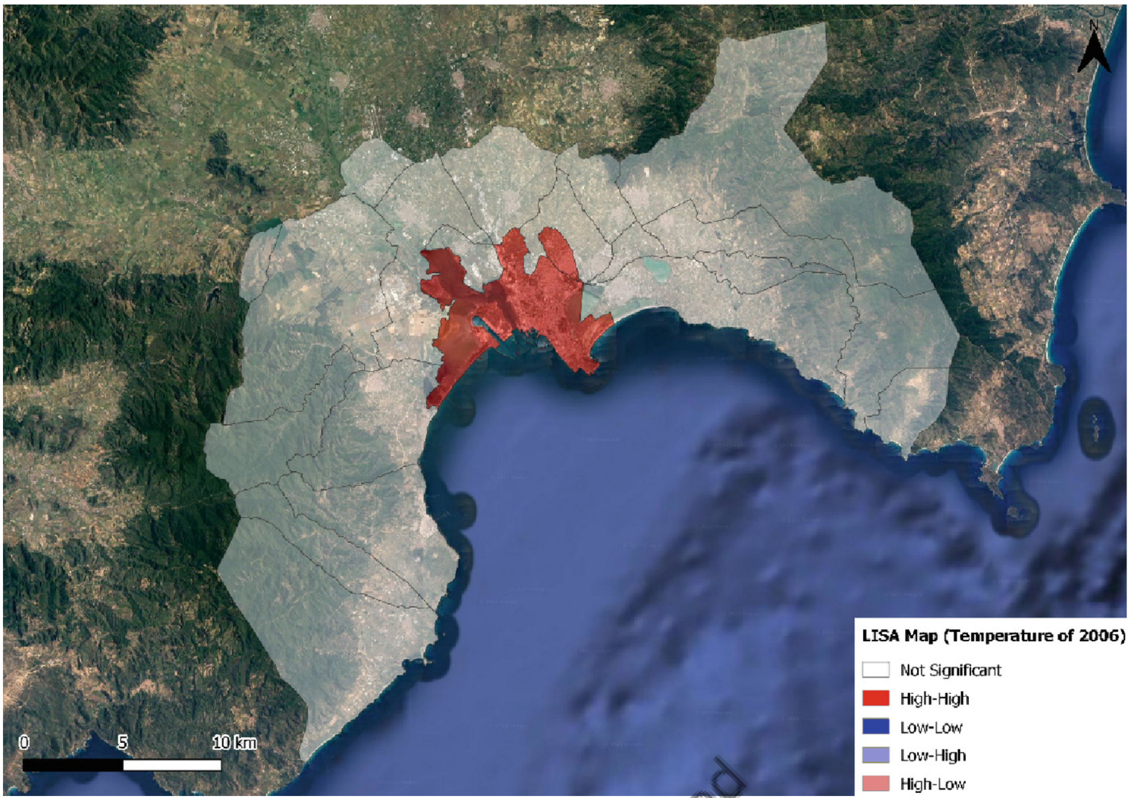


Fig. 5. Spatial autocorrelation of temperatures (2006) (Authors: Sinatra M., 2023).

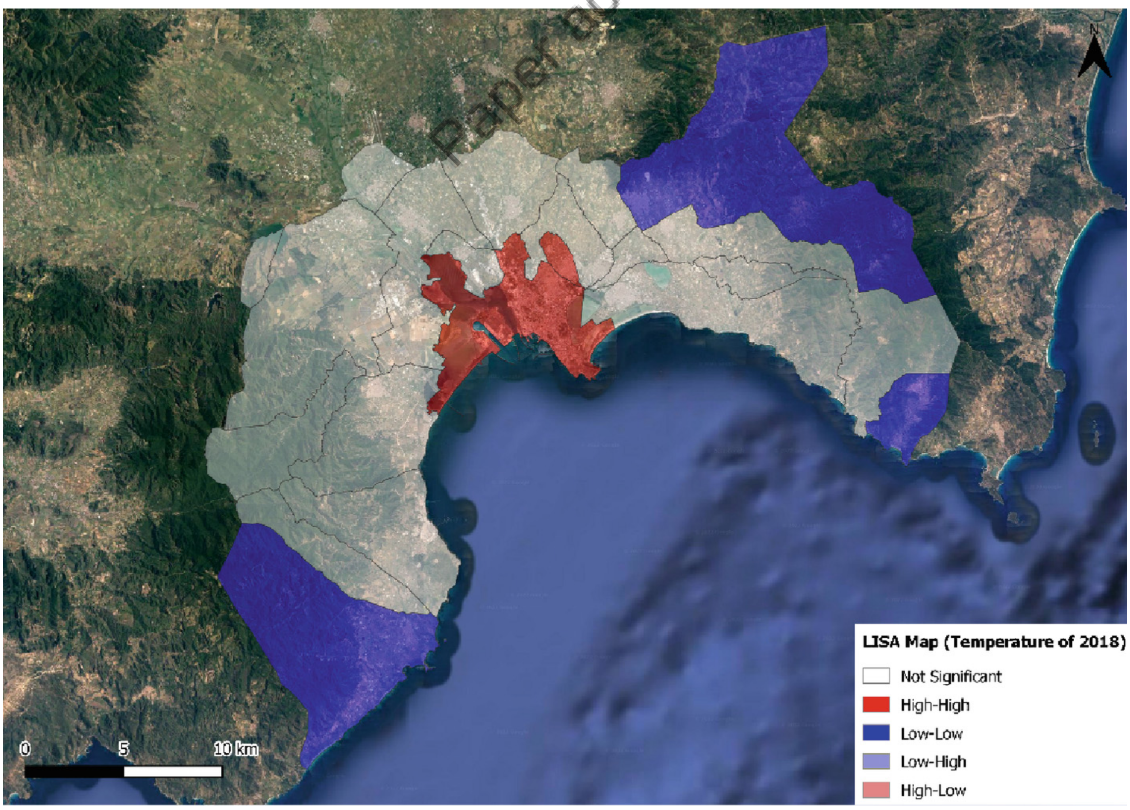


Fig. 6. Spatial autocorrelation of temperatures (2018) (Author: Sinatra M., 2023).

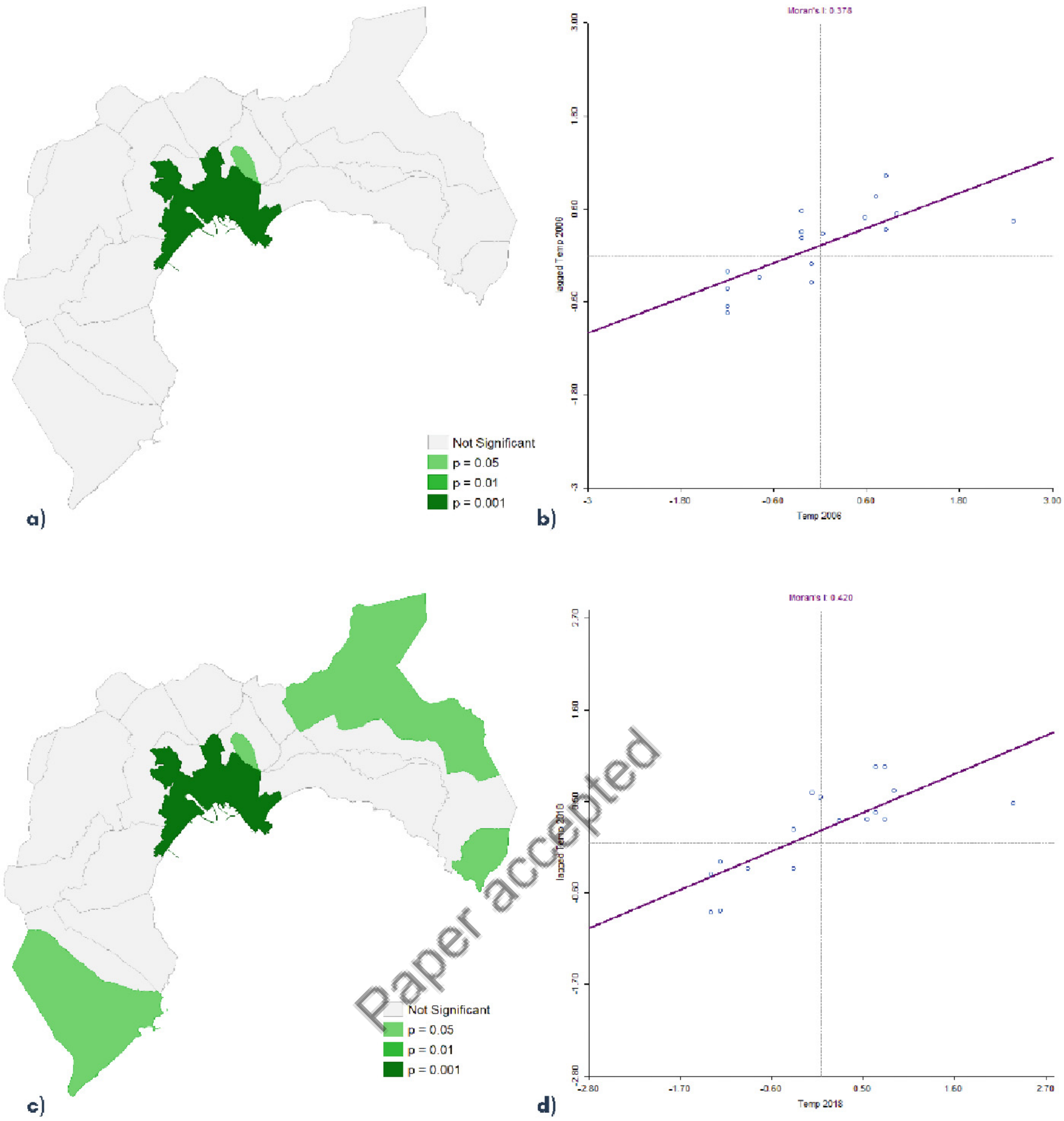


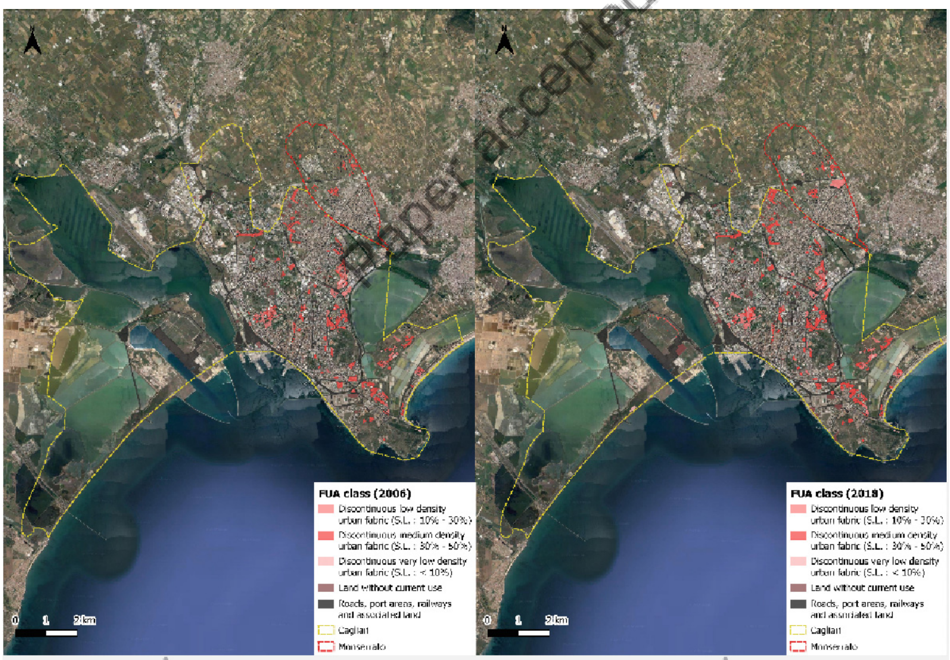
Fig. 7. LISA Significance Map and Moran's I Scatterplot.Significance maps years 2006 (a), 2018 (c), Moran's I scatterplots 2006 (b), 2018 (d).

For the Municipalities of Cagliari and Monserrato with high-high spatial autocorrelation of temperatures, the Climate city interaction assessment was carried out, using the set of indicators, as shown in Fig. 8.

The results of the evaluation of the climate-city interaction (Cagliari and Monserrato) were also spatialized (Fig. 9, Fig. 10, Fig. 11 and Fig. 12) to support MEC monitoring.

CRITERIA	INDICATORS	PERCENTAGE CHANGE (YEARS 2006-2018)
1. Land take	1.1 Airports	+ 0%
	1.2 Continuous urban fabric (S.L. : > 80%)	+ 1%
	1.3 Discontinuous low density urban fabric (S.L. : 10% – 30%)	+ 19%
	1.4 Discontinuous medium density urban fabric (S.L. : 30% – 50%)	+ 6%
	1.5 Discontinuous very low density urban fabric (S.L. : < 10%)	+ 53%
	1.6 Industrial, commercial, public, military and private units	+ 3%
	1.7 Isolated structures	+ 5%
	1.8 Land without current use	+ 30%
	1.9 Roads, port areas, railways and associated land	+ 5%
	1.10 Sports and leisure facilities	+ 4%
	1.11 Water	- 1%
2. Green Areas	2.1 Forests	+ 0%
	2.2 Green urban areas	+ 0%
3. Sustainable energy	3.1 Bioenergy	+ 77%
	3.2 Eolic	- 67%
	3.3 Photovoltaic	+ 99%
	3.2 Hydroelectric	- 98%
4. Greenhouse gas emission	4.1 CO2 emissions	- 33%

Fig. 8. Municipalities of Cagliari and Monserrato: Evaluation of climate-city interaction (2006–2018) (Authors: Sinatra M. and Balletto G., 2023).



CRITERIA	INDICATORS	PERCENTAGE CHANGE (YEARS 2006-2018)
1. Land take	1.3 Discontinuous low density urban fabric (S.L. : 10% – 30%)	+ 19%
	1.4 Discontinuous medium density urban fabric (S.L. : 30% – 50%)	+ 6%
	1.5 Discontinuous very low density urban fabric (S.L. : < 10%)	+ 53%
	1.8 Land without current use	+ 30%
	1.9 Roads, port areas, railways and associated land	+ 5%

Fig. 9. Land use - FUA class of 2006 and 2018 (Author: Sinatra M., 2023).

The focus was therefore on the two municipalities of Cagliari and Monserrato. Also the following spatial representations, as a consequence, reflect this spatial selection and thematic representation.

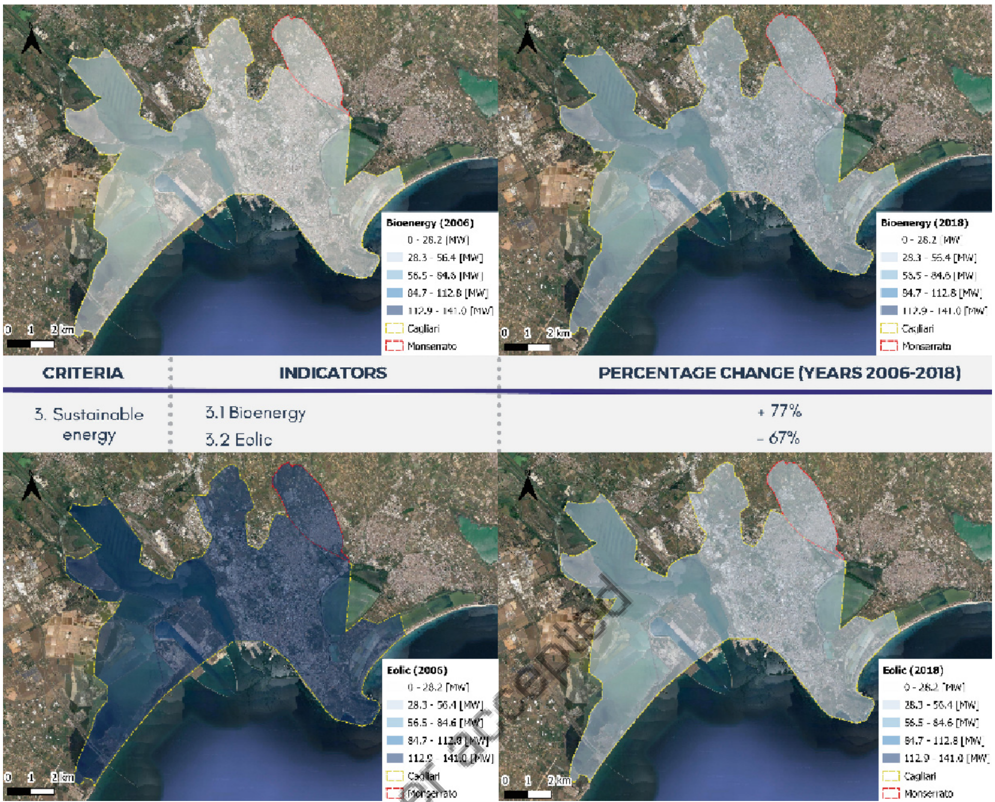


Fig. 10. Sustainable energy production for renewable sources of bioenergy and eolic, years 2006 and 2018 (Author: Sinatra M., 2023).

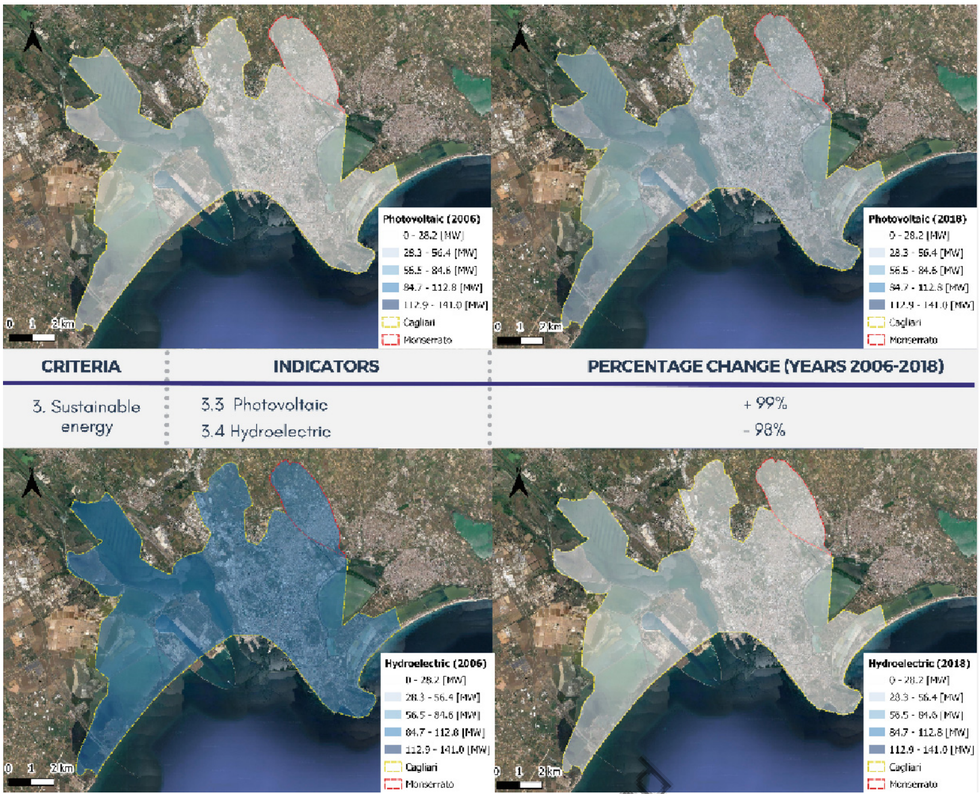


Fig. 11. Sustainable energy production for renewable sources of photovoltaic and hydroelectric, years 2006 and 2018 (Author: Sinatra M., 2023).

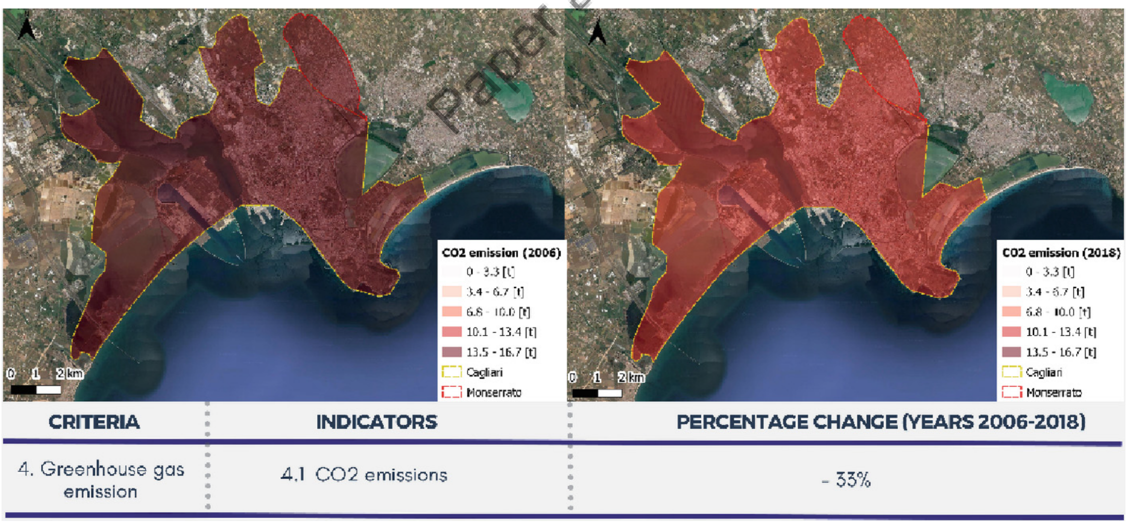


Fig. 12. Tons of CO2 equivalent per person, years 2006 and 2018 (Author: Sinatra M., 2023).

5 Conclusions and Future Development

In Italy, with Legislative Decree 50/2016, it is mandatory to apply the MECs to projects and works for the new construction, renovation and maintenance of buildings and for the management of public administration construction sites. The MECs constitute the environmental requirements useful for identifying the design solution, the product or service that demonstrates the best attention to the life cycle of one or more buildings to be built up to urban regeneration. The latter is to be preferred over the former, because it limits soil consumption to protect environmental sustainability. Urban regeneration also allows the community to reappropriate and relive the regenerated spaces again, with evident improvements in the quality of life and in the social, economic and environmental spheres. In fact, urban regeneration is finding an important space in national and regional legislation. At a central level, the Decree law 18 April 2019, no. 32, "Urgent provisions for the revitalization of the public contracts sector, for the acceleration of infrastructural interventions, urban regeneration and reconstruction following seismic events", set the Government's objective to reduce land take in favor of regeneration of the existing building stock by encouraging rationalisation, promoting and facilitating the redevelopment of degraded urban areas. For this reason the MECs of urban regeneration projects are more powerful than the MECs referred to new construction projects.

However, the urban complexity requires a representation of the territorial context, in order to guarantee the monitoring of the MECs. In fact, the assessment of compliance with the minimum environmental criteria requires to be correlated with the context in order to obtain a real containment of the effects on the environment [7, 42]. In particular, the analysis of the reference context and the basin of influence of urban projects also represents the challenge for regeneration projects [43], so much so that compliance with the minimum environmental criteria must therefore be associated with the context similarly to other tools such as the EIA, evaluation of environmental impact [44]. In this sense, this manuscript intends to provide a first contribution, which will be the subject of subsequent developments and applications to case studies to further test the proposed model.

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