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Monitoring and modeling urban sprinkling: a new perspective of land take

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Summary

Foreword

Since 2017, the PhD activities outlined in this thesis have involved a first cognitive phase of analysis of the research topic land take focusing on the urban sprinkling dynamics. A great work of construction and reconnaissance of data has been done in order to assess the dynamics of settlement development in Basilicata region from the 50s to 2018. New components have been added to the traditional settlement system components, such as renewable energy sources, which, if not planned and regulated at local or at least regional level, generate irreversible damage to land take. The research is mainly focused on the analysis of the settlement evolution in low-density context in the absence of settlement demand and that generates fragmentation from all points of view (landscape, urban, infrastructure). The urban sprinkling is a dynamic recently introduced in the scientific literature but that well represents low-density contexts such as the Basilicata region. It emerges an unsustainable character of urban sprinkling from a social, environmental and economic point of view. The following sub-section will highlight the originality of the research through a quantitative analysis of the main literature in Scopus with the terms urban sprawl and urban sprinkling. It will be highlighted how the theme of urban sprinkling is still little explored compared to that of urban sprawl. Subsequently, the hypothesis of the thesis and the main objectives pursued will be discussed; the structure of the thesis will be described and the main results obtained will be exposed.

The results of this thesis have been published in several scientific articles (see Supplement section).

a. *Research framework: Sprawl vs. Sprinkling quantitative analysis of the main literatures in Scopus*

In this section will be analyzed the bibliographic impact, in quantitative terms, of some research fields concerning the area of interest of urban studies. The analysis will be made on the basis of the Scopus database of the Elsevier (last access on the 20th October 2020) publisher and will focus specifically on the research fields related to urban expansion and transformation processes like “urban sprawl” and “urban sprinkling”. The objective is to o highlight the most explored themes and those still little explored in the field of urban expansion and transformation dynamics.

In the area of interest of urban studies, the research field of urban sprawl has been widely explored. Indeed, urban sprawl is one of the most widespread patterns of urban expansion and transformation that has affected (and still affects) many metropolitan areas in recent decades, leading to several critical impacts, such as land consumption, loss of high quality agricultural and natural areas, landscape fragmentation and loss of ecosystem services [1–4].

A quantitative assessment in Scopus shows that there are 4791 (October 2020) scientific articles that contain in the title, abstract or keywords the term "urban sprawl". The first articles date back to the 50s and concern the research field of medicine and public health. One of the first articles effectively related to the area of interest of urban studies was published in geography field. it is the one of Sinclair that in 1967 [5] identified the phenomenon of urban sprawl as the process of natural expansion of metropolitan areas as a function of population growth. In addition, particular attention is paid to the conversion of agricultural land into urban areas close to metropolitan cities. Among the most cited articles we mention Ewing's 1997 article [6], which is basically a review in which the main causes of the sprawl are described in relation to a specific context that is Los Angeles city. Differently, Galster et. al., in 2001 [7] (one of the articles with more citations), present a conceptual definition of urban sprawl proposing different indicators on which sets the thresholds and address the problem of the semantic operability of the term "urban sprawl" that they try to group in six general categories of definitions. More recent is the article by Jaeger et. al, [8] (see

Glossary section) which in 2010 aims to provide an univocal definition of urban sprawl through the analysis of several existing definitions and defines thirteen suitable criteria for the measure of urban sprawl.

Most of the articles in this research field have been published since 2005 (78% of the total). The subject areas with more articles are Social Sciences (27.7%), Environmental Sciences (21.4%), Earth and Planetary Sciences (10.9%) and Engineering (8.7%). The remaining part (31.3%) covers, with small percentages, various thematic areas including: energy, computer science, mathematics, decision sciences, etc. Analyzing the countries of authors (not the case studies analyzed in the articles) we note that 31% are from America, 29% from Europe (of which 21% from Italy) and 15% from China; the remaining 25% is of different origin countries. Among all the articles analyzed, excluding the term "urban sprawl", the keywords most present are: "Urbanization", "Remote Sensing", "GIS", "Land Use" and "Urban Growth". In the word cloud in the Fig. 1, are represented all the keywords individuated in the articles analyzed. As the use intensity of the keyword varies, the size of the text changes.

Fig. 1 Word cloud of keywords used in articles searched with the term "Urban Sprawl"

While the terms "Urbanization", "Land Use" and "Urban Growth" are inherent to the dynamics of urban sprawl and describe the phenomenon in qualitative terms to integrate its meaning [9–11], the terms "Remote Sensing" and "GIS" are more related to operational and computational processes for the quantitative evaluation of the phenomenon [12,13]. The research does not highlight terms strongly related to urban sprawl such as "Land Take", "Soil Consumption" or "Soil Sealing". Only 32 articles contain simultaneously the terms "Urban Sprawl" and "Land Take" and 74 articles contain the terms "Urban Sprawl" and "Land consumption" simultaneously. Why is this occurring? The reasons are multiple and linked to different variables. Below we try to hypothesize some of them. Ewing in 1997 [6] defines the sprawl as: "*the spread-out, skipped-over development that characterizes the non-central city metropolitan areas and non-metropolitan areas of the United States*". This assumes that the phenomenon of urban sprawl has been studied (mainly in the past) in relation to the traditional urban sprawl dynamics of cities in the United States. Urban sprawl is therefore an expansion dynamic, a form of transition of land cover from a natural or semi-natural cover to an artificial land cover that, of course, produces land take and consumption. In order to act on soil consumption, it is first of all necessary to act on the phenomena that regulate it and so on the dynamics of expansion such as urban sprawl. For this reason, the number of researches on urban sprawl is too much higher than those that contain the terms land take, land consumption or land use. In addition, often, due to the lack of a clear and shared definition of the terms, it is difficult to address issues such as land consumption and urban sprawl. Often the term urban sprawl is used to refer to land consumption and vice versa. Urban sprawl remains the main cause of soil consumption since it is characterized by low settlement density indexes that often involve the construction of new infrastructure services and therefore, an overexploitation of the soil resource[14–17]. it is representative of an unsustainable transformation dynamic. Table 1 shows in the diagonal the number of articles present for each keyword analyzed (the keyword is contained in the title and/or abstract and/or among the keywords of the article). In the rows and columns, it shows, instead, the number of articles containing simultaneously the two keywords that cross each other.

Table 1 Summary table of the number of articles searched in Scopus based on the keywords identified in the rows and columns. The table is updated to October 2020

	Urban Sprawl	Land Take	Land Consumption	Urban Dispersion	Soil Consumption	Urban Shrinkage	Urban Sprinkling
Urban Sprawl	4791	32	74	22	26	14	9
Land Take	32	233	15	0	6	0	10
Land Consumption	74	15	392	4	8	3	1
Urban Dispersion	22	0	4	322	1	0	0
Soil Consumption	26	6	8	1	172	0	0
Urban Shrinkage	14	0	3	0	0	228	0
Urban Sprinkling	9	10	1	0	0	0	15

We want to pay particular attention to the term "urban sprinkling" which is the subject of this research and is still little explored as a research field. There are only 15 articles with this keyword and the first article is from 2015. Romano et al. in *"Geografie e modelli di 50 anni di consumo di suolo in Italia*[1]*"* [18], in fact, use for the first time the term urban sprinkling to define a transformation dynamic different from the more traditional and widely studied urban sprawl dynamic. They define, in this article, the values of building density, residential density and coverage ratio that differentiate the urban sprawl dynamic from that of urban sprinkling. The same authors, in 2017, identify in a purely geometric formula the phenomenon of urban sprinkling, through the use of the Sprinkling Index that they apply to the case study of the Umbria region [19] and, in another article propose possible solutions (the de-sprinkling process) to be introduced in decision support systems to limit and regulate the expansion processes in the medium term [20]. In these articles, since 2015, have been investigated and declined the forms of urban expansion of the Italian model, one of the most significant in Western Europe for which the new definition of urban sprinkling has been proposed. Since 2017[2], as the subject of this PhD thesis, the sprinkling index was recently tested in the context of the Basilicata [21] region where the cost of urban sprinkling was also calculated on small sampling [22]. In the Basilicata region, moreover, the sprinkling index has also been declined on different settlement system components represented by renewable energy plants [23] and oil wells [24]. In addition, Urbieta et.al. in 2019 identified the phenomenon of urban sprinkling in the Portugal continent [25]. It is evident from the number of existing articles with the term "urban sprinkling" that this research area is still little explored. From the analysis of the keywords

[1] This article is not available directly in the Scopus database as it is not indexed by Scopus, it is a secondary document.
[2] 2017 corresponds to the year of the PhD start.

most present in the articles emerges (in addition to urban sprinkling) the term fragmentation and land take (see Fig. 2). In many articles, in fact, the sprinkling index has been used to quantify the fragmentation process caused by urban settlements. Furthermore, the urban sprinkling is typical of "urban rural pattern" in a "low density" context which are a representative keyword of this research.

Fig. 2 Word cloud of keywords used in articles searched with the term "Urban Sprinkling"

All the articles on urban sprinkling come from Italian country; only one from Portugal continent and one from Africa [26] where there is mention of the phenomenon of urban sprinkling but without any further investigation.

b. General hypothesis and main research objectives

According to the studies done so far on the recent urban transformation dynamics, namely urban sprinkling, this thesis aims to investigate the phenomenon from different points of view to bring out its unsustainable character. The urban dispersion phenomena, specific characteristic of low-density territories, will be examined through the sprinkling index by including new components in addition to the traditional settlement system components. It allows to evaluate the shape of the anthropic settlements and the distance between them which often results in fragmentation of the urban settlements which in turn generate landscape fragmentation. Nowadays, both in the proximity of large cities and in more external areas such as rural areas, there are often evidences of strong fragmentation of the anthropic settlements in which, even if the amount of occupied surface (land take) may not seem worrying, its configuration determines a general decrease in ecological connectivity, landscape quality and general degradation of soil functions.

The general hypothesis is that fragmentation (of urban, landscape and habitat) can become an indicator of land take. In fact, it is not enough to consider only the loss of natural or agricultural areas, but also the distribution of buildings in the landscape matrix, i.e., its spatial component. An emblematic case is that of Basilicata region whose dynamics of transformation from the 50s to the present day will be investigated in this thesis. According to the latest report of the Italian Institute for Environmental Protection and Research (ISPRA 2020), the Basilicata region has only 3.15% of land consumption compared to the entire regional surface. This indicator is in contrast with the shape of the anthropic settlements which results fragmented and dispersed. It is essential that the effects of fragmentation as well as ecosystem disaggregation take on a "measurable" character, joining the list of indicators of urban and territorial quality such as land take and land consumption that European Union addresses to national communities currently consider essential and decisive to highlighting the efficiency/inefficiency of environmental and landscape management.

It is crucial to understand and investigate what have been and will be in the future the most influential drivers on these dynamics that contribute intrinsically to land consumption and to define the addresses or the thresholds to contain this pulverized and disordered dissemination of anthropic settlements.

c. General structure of the thesis

The thesis has been structured as follows: 6 chapters introduced by an abstract in which the main objectives and the main results obtained as well as continuity with the previous chapter are presented. The thesis is also accompanied by an appendix containing methodological and technical annexes, a glossary containing definitions of the main terms used, highlighted in the text in bold italics. Specifically, the research was articulated in different phases of work, the results of which are reported in the chapters in which this thesis is composed: (*i*) cognitive and exploratory phase: this phase is aimed at defining the scientific reference framework on the issue of land take (Chapter 1). This is a topic of particular interest in the sphere of territorial planning, also following the European strategies and regional guidelines aimed at limiting soil consumption, and the urban planning tools that currently govern the management of soils at national and European level. Particular importance is given to the dynamics of urban transformation (urban sprawl and urban sprinkling) that in particular contexts highlight the weakness of the legislative framework. (*ii*) phase of knowledge construction: aimed at the realization of a taxonomic scheme and a thesaurus for the construction of an ontology (Chapter 2), necessary to adequately manage the issues related to the territory and its transformations. (*iii*) methodological and experimental phase in which the dynamics of urban expansion and transformation from the 50s to 2018 were examined. At the national level, settlement dispersion will be analyzed with indices of spatial autocorrelation (Chapter 3), and at the regional level (Basilicata region) the dynamics of fragmentation will be analyzed with sprinkling index and other indices proposed in the literature (Chapter 4). Finally, in Chapter 5 a methodology for modeling urban sprinkling to 2030 with multinomial logistic regression and cellular automata is proposed.

The Chapter 6 concerning the conclusion is divided in principals results of the thesis and cconsiderations and main remarks on urban sprinkling as a new perspective of land take.

d. Research results in brief

- Semantic conflict in the definition of terms related to land take emerges.
- According to the global Moran index, all regional and provincial territories present a dispersed spatial configuration. 63% of the provinces follow the dynamics of urban sprinkling while the remaining part follow the dynamics of urban sprawl.

- The Basilicata region has the highest degree of urban dispersion coupled with a low percentage of urbanized area in 2019.
- Between the 50s' and 2018, the median value of the sprinkling index increases by 54% translating into an increase in total fragmentation caused by anthropic settlements.
- The installation of new renewable energy plants produces additional fragmentation that from 2008 onwards begins to replace the sprinkling generated by the traditional components of the settlement system (residential and industrial buildings).
- Following the infrastructural fragmentation index, the greatest variations occur in correspondence with the construction of new renewable energy plants.
- According to the landscape metrics and the diversity indices it emerges that landscape fragmentation in the Basilicata region is constantly increasing.
- The results of the multinomial logistic regression show a low correlation of socio-economic variables on all expansion processes.
- The driver that most influences urban expansion dynamics is proximity to local roads. Relationship that corresponds to urban sprinkling in which new settlements tend to be built close to local roads (with less availability of services) and away from the main public service centers with an increase in social costs.

1. Land take and urban transformation dynamics. An overview

This chapter provides a general overview of the land take phenomenon in Europe and Italy. Particular attention is paid to the dynamics of urban expansion from the best known and studied, the urban sprawl, to the most recent and still little explored, the urban sprinkling. Characteristic of contexts with low settlement density, urban sprinkling contributes to land take and landscape fragmentation. It emerges that the legislative framework has so far not been able to control this phenomenon and in contexts rich in natural resources, the traditional components of the settlement system are joined by new components such as renewable energy that highlight the weaknesses of current legislation. These, in fact, if not regulated in the correct way generate adverse effects such as land take, the landscape fragmentation and, more generally, the loss of ecosystem services.

The great interest in land take and, more generally, in the processes of urban expansion and transformation, is due to the dimensions of the phenomenon on a global scale. Today, more than half of the world's population (55%) lives in urban areas. This percentage was only 30% in 1950, and estimates indicate that it will rise to 68% by 2050. It is also expected that in 2030 there will be 39 megacities, 9 more (cities with more than 10 million inhabitants) that will have 9% of the world's population, contributing 15% of the world's GDP. It is estimated that there will be 3% of the earth's land take [27]. Considering the recent effects on cities and daily life produced by the spread of the COVID-SARS2 pandemic these predictions could be reconsidered. There seems to be an emerging trend of an exodus of inhabitants of western megacities to rural areas. This would lead to the crisis of the megacity model, based on an unsustainable density and concentration of people. Despite the fact that, less than a year after the start of the pandemic, it is not possible to make reliable projections on a possible inversion of the trend, the possible phenomenon of the exodus from mega-cities remains worrying. This phenomenon would inevitably have effects on the environment and quality of life that would be reflected in the mobility and expansion of rural areas, both in the short and long term. All this would lead to the development of low-density settlement (dispersed) cities, increasing the level of landscape fragmentation. Compared to the dispersed (fragmented) city the compact form of the city remains in fact the most sustainable way of expansion, with advantages on the quality of life (better transport, walkability, cycling, sociality, etc.), economic and social level [15,28].

Specifically, what is land take? Land take in simple words is the phenomenon of land conversion from its original (natural) use to anthropic (urban) use [29,30].

The land take phenomenon in Europe, since the 50s has been largely driven by urban expansion characterized by a sharp decrease in urban density with the decentralization of urban areas at the expense of rural ones [31,32]. This has led to changes in the shape of urban settlements from compact to fragmented and dispersed across the territory. The urban expansions of the last fifty years have broken away from the more traditional and recognized dynamics of urban sprawl, taking on different forms and very low indices of settlement density. Characteristic of internal Mediterranean areas is the phenomenon of urban sprinkling [33], recognized for the first time in Italy by Romano et al., and studied in Spain and Africa [19,21,25,26].

Urban transformation dynamics, sprawl vs sprinkling

Since the beginning of the 21st century, the dynamics of urban expansion are no longer linked to the real need for new expansion areas resulting from population growth. On the contrary, new urban transformation is strongly correlated to the low demand for new housing in a spatial planning system that is often ineffective in guiding efficient urban development or in limiting and controlling speculative real estate initiatives. Considering the main dynamics of urban transformation, urban sprawl is more widespread in the vicinity of cities with high territorial density; on the other hand, in the vicinity of cities with low settlement density, the dynamics of urban transformation follow the phenomenon of urban sprinkling. Both phenomena affect rural areas near urban centers with the construction of new residential settlements far from existing public services and characterized by low levels of accessibility. They are characterized by low (urban sprawl) and very low (urban sprinkling) population density and building density indices.

Many authors have analyzed the phenomenon of urban sprawl [4,7–9,34–38] from different points of view, producing a shared definition: "*the spread of urban developments (such as houses and shopping centers) on unbuilt land near a city*" (Merriam Webster) [39]. More detailed definitions of urban sprawl are those proposed by the European Environmental Agency (EEA) in 2004 [40] and in the report on land recycling in Europe 2016 [41] resulting from the article of Jaeger et. al., 2014 [42] (see Glossary section for details). The urban sprawl phenomenon concerns the rapid and disorderly growth of the city, concentrated mainly in suburban areas with low population density affecting the border areas located at the edge of the city [43]. It consists of a urbanization pattern characterized by an unplanned and disorganized structure, a low population density (between 20 and 150 inhabitants per hectare) and a discontinuous building settlement (with densities between 6 and 12 buildings per hectare) that originally spread along transport infrastructures and haphazardly occupied large portions of the territory [18].

The transformation dynamics occurred (mainly) in some regions of central-southern Italy in the second post-World War period led to phenomena of settlement dispersion different from those of urban sprawl, so that the new concept of urban sprinkling was coined [44]. The phenomenon of urban sprinkling can be defined as "a small quantity distributed in drops or scattered particles" [18]. It can be considered as a kind of " pulverization" of anthropic elements on the territory and it is the dynamic that best represents the configuration of most of the Italian territory and other Mediterranean country of Europe. This phenomenon mainly affected the regions of central and southern Italy both inland and in coastal areas. It is typical of regions with very low settlement density (between 0.1 and 0.8 buildings per hectare) and population density (between 0.2 and 2 inhabitants per hectare) whose territory is fragmented by settlements scattered uncontrollably in the rural landscape [18]. In some cases, such as urban sprawl, this phenomenon has originated from weak urban planning, in others it has been the consequence of abusive initiatives, encouraged by amnesties for the violation of planning regulations.

Knowledge of the different urbanization forms/dynamics is the basis for being able to effectively deal with the question of the sustainability of an urban development model. As there is only a non-objective definition of sprawl [7,45], a series of indicators have been proposed to quantify it, ranging from single to multidimensional metrics [8,12,37,46–48], and sometimes the results are contradictory in measuring the expansion of certain cities [49]. As concerns urban sprinkling, an indicator that has already emerged as effective in expressing the transformation dynamics and territorial fragmentation is the Sprinkling index (SPX) [19].

1.1. Are we ready for "No net Land Take by 2050"?

As highlighted in the previous section, the phenomenon of land take is becoming increasingly widespread worldwide despite the implementation of various policies to contain/limit its consumption [27,30,50,51]. The European Commission has legislated for soil protection by setting a target of zero net soil consumption by 2050 (EU Environmental Action Programme to 2020 (7th EAP)). This goal can be achieved by aligning land take increasing with actual population growth by 2030. In recent years, following the provisions of the EU, spatial development in Europe is increasingly oriented towards the logic of containment of urban sprawl and regeneration of existing buildings, although there is still much to achieve. Demographic trends are crucial in the urban expansion process of a territory. In Italy, but also in other European countries, urban expansion is increasingly in absence of a real settlement demand [52,53]. In many contexts of low density and continuous de-population, urban expansion is accompanied by a negative demographic trend (decoupled growth) [21,54,55].

Land take is complex in its identification and unambiguous definition. A sort of semantic conflict has developed over time which contributes to confusion about the amount of land consumed and the most robust indices for its quantification. This contributes to slowing down the achievement of the objectives imposed by the EU since each state and within it each small administrative unit legislates in different manner. As a matter of fact, the semantic conflict about the concept of land take emerges in regional laws and land take laws proposed. As an example, the EU defines "land take" - both in the report on *land recycling in Europe* 2016 [41] and in the *Guidelines on best practice to limit, mitigate or compensate soil sealing* in 2012 [29] - using the term "land consumption" to define it. The EEA defines "land consumption" differently from "land take". While the "land take" refers to those areas that are taken away for purely artificial uses that provide for total soil sealing, "land consumption" refers to the consumption of land cover including areas consumed for new expansion (sealing), for the intensive use of land due to agriculture, forestry and other economic activities as well as other intensive uses such as pastures [40] (see
Glossary section for detailed definitions). In this research, we use the definition of "land take" and "land consumption" proposed by EEA.

According to EEA, in Europe, despite a reduction in the last decade (land consumption was more than 1000 sq km per year between 2000-2006), land consumption in the EU28 still amounted to 539 sq km per year between 2012 and 2018. Between 2012 and 2015, moreover, landscape fragmentation continued to increase, in the 39 countries of the European Economic Area, particularly affecting rural and low-populated areas. In 2015, there were about 1.5 fragmented landscape elements per km2 in the EU, an increase of 3.7% since 2009. In addition, about 1.13 million sq km, (28% of the EU surface), was highly fragmented in 2015, an increase of 0.7% compared to 2009. In Italy the situation is not so different. Compared to Europe, Italy ranks 22nd (out of 39 countries in the European Economic Area) for soil sealed between 2000 and 2018 (175.7 sqm/sq km) [56].

Italy is still far from the EU objective "No net land take by 2050”. According to Italian Institute for Environmental Protection and Research (ISPRA), in 2019 in Italy, the soil was consumed at a speed of 2 sq m per second for a total of irreversibly impermeabilized surface (land take) equal to 57 million sq m [57].

The European Commission (EC) has recently (2020) adopted the new EU Biodiversity Strategy 2030 and its Action Plan - a comprehensive, ambitious, long-term plan to protect nature and reverse ecosystem degradation [58]. In the report, the EC states that natural resources have suffered a decline since the 50s that is unprecedented in human history. One species out of eight is at risk of extinction.

Among the direct causes of the loss of biodiversity are undoubtedly the land take and land transformation, over-exploitation of resource, climate change, pollution and invasive alien species that are rapidly disappearing from the natural environment. These phenomena are evident: green spaces are being sealed and nature reserves are disappearing due to new expansions. For the Italian territory, the trend is extremely negative, caused by the sharp deterioration of the elementary indicators related to land fragmentation and land consumption.

In Italy, the oldness of the legislation concerning land management poses new challenges to policy makers. The provisions that regulate the national urban planning, from Law 1150/1942 to DM 1444/1968, are no longer suitable to govern the development of cities and even less to ensure the competitiveness of the territories. The expansive territorial model, at the basis of the national urban planning legislation since 1942, is giving way to planning guidelines that require to give priority to the transformation and reuse of the built city, allowing the use of new territorial resources only in cases where there are no alternatives to the reorganization of the existing settlement fabric.

Several efforts have been made at the national level, numerous draft laws have been presented in Parliament concerning provisions on the containment of land consumption and urban regeneration, but they are struggling to make their way and remain stuck in the drawer. Only at the regional level there have been several efforts to approve laws on the containment of soil consumption, but it is clear that in the absence of a national legislation it becomes difficult to build a kind of homogeneity throughout the territory.

1.2. New settlement system components bring out the weaknesses of the current legislative framework

Recent studies [59–62] have proposed a critical review of the Italian planning system which lack the capacity to be associated with current topics related to social, technological and environmental innovations that generate significant territorial transformations. In sharing this critical position that has highlighted how the Italian planning system has marked a relevant delay in upgrading its normative framework for an effective territorial management, and in comparing with Great Britain [63,64], France [65,66], Germany [67–69] and other European countries [70–72], attention is focused on the evidence of territorial transformations due to those settlement system components different from the more traditional ones (residential and industrial buildings, and transport infrastructure). Reference is made to the territorial transformations that took place following the great impulse of the energy sector that led to the installation (in some cases in uncontrolled manner) of plants for the production of renewable energy and for the production and extraction of hydrocarbons. The post-war economic upswing and the development of technologies based on the use of fossil fuels in Italy have driven technological progress towards the exploration of geo-mineral resources with consequent large investments in the hydrocarbon sector [73]. The current urban planning system, based on the traditional components of the settlement system (in a word "zoning"), has not supported any rational and effective decision-making process with regard to the management of hydrocarbon wells and installations of renewable energy plants (RES).

The complex interaction between the weakness of national, regional and urban planning, the social dynamics, the often unintended consequences of sectoral policies and the related market forces are reflected, in many Italian contexts, in a strong settlement inefficiency [2,19,22,60,74–76].

The rapid growth of renewable energy, which has allowed Italy to reach the EU 2020 target, has led to a widespread and dispersed installation of energy production plants, stimulated by economic incentives and simplified authorization procedures. These new transformations represent a growing challenge for regional planners and administrators. How to manage the transformation of the landscape dictated by global objectives to be achieved, in order to find an effective and sustainable solution for renewable energy technologies at local level?

In the case of RES this question is significant, because, while RES installations contribute to solving the global climate change problem and reducing carbon emissions, at local level they imply significant impacts on several components such as: land use, land occupation, loss of aesthetic values and habitat quality [77,78]. The intensity of these effects depends on many variables. It is important, therefore, to discuss whether the intensity of negative impacts at local level is more related to the technical characteristics of each installation or their spatial distribution. These transformation processes are a consequence of the development policies of the energy sector and lead to land take, fragmentation of the territory, fragmentation of human settlements and generalized landscape impacts, often exacerbating the fragmentation already produced by the traditional settlement system components. This framework provides a set of global objectives and opens the search for solutions for the local context. Priority focus refers to those vulnerable local contexts where the abundance of natural resources (nature, water, landscape, protected areas, etc.) is associated with a weak spatial planning system that is unable to generate and manage sustainable transformation of the territory.

These considerations relaunch the planning discipline necessary for new tools that provide effective responses to the demand for new planning objectives: land consumption [79–83], quality of urban life [84,85], urban adaptation to climate change [86,87], safeguarding ecosystem services [88–92].

2. An ontology on land take

Considering the importance of the land take issue and the legislative weakness emerged in the previous paragraph in terms of land consumption and transformation dynamics, it seems necessary to build a clear and efficient model that can support policy makers in the choices of land governance. In this regard, starting from the transitions triangle that describes the intensity of transformations, a taxonomic scheme was built followed by an ontology on land take.

This chapter presents the construction of a taxonomic scheme starting with the transition triangle and proceeding to model an ontology on land take, considering processes, policies, and strategies. According to Guarino (1998) [93], an ontology can be defined as "*an engineering artifact, consisting of a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions about the intended meaning of the words in the vocabulary"*. Other two important definitions are those of Gruber (1993) [94], who defines an ontology as *"a specification of a conceptualization"*, then improved by Borst (1997) [95] who considers an ontology as *"a formal and explicit specification of a shared conceptualization"*. In computer science, the term ontology specifically refers to an attempt to formulate an exhaustive and rigorous conceptualization within a given domain. It is generally a hierarchical data structure that contains all relevant entities, the existent relationships between them, and domain-specific rules, axioms, and constraints [96–98]. The Construction of an ontology is finalized to guarantee the interoperability between the systems, defining in univocal way the concepts and deepening them. It is necessary, therefore, the investigation of the semantic correspondences contextually to the integration of the database [99].

Ontologies are increasingly recognized as essential components in many fields of information science, they were first employed in artificial intelligence as a means of conceptualizing a part of the real world [100]. Among the various goals of ontology construction, the one of most interest to the field of spatial planning is to provide a common conceptualization of a domain on which a generalized consensus emerges. Ontologies can be considered as artifacts of the knowledge engineering useful to manage and arrange the fields of spatial information systems planning, integrate different systems, retrieve information and facilitate semantic interoperability. To implement an ontology, it is necessary to formalize some mental models within a group, aiming to collect domain knowledge and providing a common vision, which can be reused and shared by other groups [101]. When a more extensive agreement between several groups is reached, a semantic correspondence is achieved, at the expense of part of the original meaning or with loss of some levels of detail [102].

An ontology is an explicit formal description of a domain of interest that allows to specify: classes (i.e. the concepts of the domain), semantic relations between classes (semantic graph), properties associated with a concept (attributes and possible restrictions), possible logical level (axioms, inference rules) and the instances of the classes [103]. It can be seen as a hierarchically structured set of terms for describing a domain, to be used as a knowledge base framework [104]. We move, therefore, from a pure list of concepts, which is the first thing that is spontaneously done in producing a glossary, to a restructured vocabulary.

According to Jannink (1999) [105] in this research, the ontology was developed based on a methodology to convert a dictionary into a directed graph, which could be considered as a first draft of an ontology. For graph extraction, each word and definition group are transformed into a node and each word at a definition node is transformed into an arc at the node that has that head word. The purpose of this section is to provide a useful tool for the clear and complete definition of land take related to the processes of land transformation that shape the lives and activities of people and their interactions with places and nature. Various concepts/definitions are defined within the ontology, since land take is a very broad and complex topic as it affects the social, political, environmental and economic spheres: this means that social relations do not operate independently from place and environment, but are completely anchored in them.

2.1. The “transitions’ triangle” and the intensity of transformations

Soil is a finite resource and the way it is used is a major driver of environmental change with significant impacts on quality of life and ecosystems [41]. Because of its intrinsic value, natural soil must be protected and preserved for future generations. Soil provides food, biomass, and raw materials for life and human activities; it is a central element of the landscape and cultural heritage; it stores, filters, and transforms many substances, including water, nutrients, and carbon; and because of their socioeconomic and environmental importance, these functions must also be protected [106]. In Europe, the proportion of land occupied for production (agriculture, forestry, etc.) is one of the highest on the planet, and conflicting demands on land use require decisions involving strong trade-offs. On the other hand, increasing artificial surfaces for new expansions often causes the compromise or interruption of important soil ecological functions, such as biomass supply, soil biodiversity and soil carbon pool or water infiltration potential. All of these contribute to the negative impacts of climate change by decreasing the potential for carbon storage and sequestration, or increasing surface runoff during flooding [29]. Covering the soil with impermeable materials (soil sealing) is probably the most impactful use that can be made of the soil resource, since it determines the total loss or a permanent degradation of its functionality such as to limit / prohibit its irreplaceable role in the cycle of nutrients. The productive functions of soils are therefore inevitably lost, as well as their ability to absorb CO2, to regulate water flows, to provide support and sustenance for the biotic component of the ecosystem.

Since the construction of the ontology on land take is the primary purpose of this section, the soil and the transformations connected to it are the fundamental elements from which to start. In Fig. 3 is proposed a re-interpretation of the transitions triangle proposed for the first time by the EEA and the

Joint Research Centre (JRC) [107,108] and further developed by the National Observatory on Land Consumption 2009 (ONCS) [109].

The first triangle of the EEA (Fig. 3 a) represents a visualization mode of the dynamics of soil coverage and transformation according to the triangle shape. In the three vertices are placed the three macro-categories: artificial soils, soils for agriculture and natural soils (forests, wetlands and water); the arrows indicate the directions of transition from one macro-class to another. The triangle proposed by the ONCS (Fig. 3 b) places in the three vertices the macro-classes of soli coverage: urban, agricultural and natural; the transformations are indicated by the arrows. The circular arrows represent homologous transformations, i.e., those occurring in the same macro-classes of land cover; the linear arrows represent transitions from one macro-class to another. The dashed arrows represent transitory transformations and the continues arrows represent permanent/irreversible transformations.

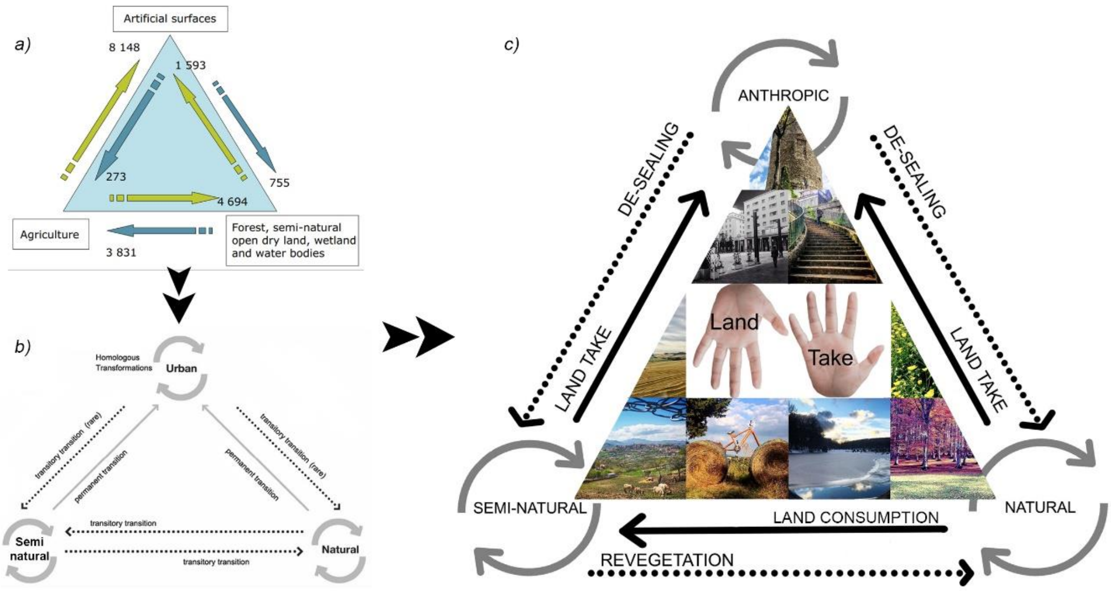


Fig. 3 Reinterpretation of the triangles of transitions proposed by EEA (a), deepened by ONCS (b) and proposed in the current research (c).

Fig. 3 c shows the re-interpretation of these triangles that has as main object the processes of land transformation, indicated in the triangle with a continuous arrow, with main reference to land take and land consumption. As already mentioned in section 1.1, the EEA defines "land take" as referring only to totally sealed surfaces, while "land consumption" also refers to changes in coverage due to intensive land use (see Glossary section for detailed definitions). This triangle represents the processes of soil transformation that directly involve the land cover, and that objectively and physically, lead to a change and then a consumption of land cover in three different macro classes placed respectively at the three vertices of the triangle: anthropic, semi-natural and natural. Two transitional processes are identified that represent the possibility of reversing the process of land take and soil consumption: de-sealing and revegetation. The de-sealing occurs when the urban macro-class transitions towards the natural or semi-natural classes and concerns the recovery of part of the previous soil sealed by removing the impermeable material that covers it as asphalt or concrete, with the aim of recovering a real connection with the natural subsoil. Revegetation occurs when the semi-natural macro class moves towards the natural one. It is understood as ecological enhancement and renaturalization of land to bring it back to

its original nature. These two processes represent sustainable strategies against soil sealing with the aim to mitigate and slow down the process and degradation of soil consumption as much as possible with the help of European, national, regional and municipal policies. In the central part of the triangle, the key word of the Land Take domain has been reported, the position of the hands indicates two conditions: the open hand towards the user (land) is a sign of offer representing all the resources that the soil can offer; the other position of the hands (take), as if to indicate a stop, refers to the taking of the soil and therefore wants to represent the stop to the irreversible exploitation of the soil resource.
In the triangle the macro-classes represent land, the continuous lines represent land transformation processes and the dashed lines represent policies and strategies to limit and regulate land consumption. As we will see in the next paragraph *land-processes-policies* will be the main concepts (super classes) in the ontology development.

2.2. Ontology development

The land take ontology identifies the main classes, organizes them hierarchically, specifies their properties and describes the relationships between these classes. It defines, in the particular application domain, the set of terms that univocally denote a particular knowledge and between which there is no ambiguity, since they are shared by the community of users of the domain itself.
The development of an ontology can be divided into four principal phases. The definition of the objectives and scope of an ontology is the basis of its construction and in fact the (*i*) first phase concerns the definition of the domain of knowledge namely the scope of ontology. The domain is the abstraction of the real system that is intended to be represented through the ontology. Based on the considerations made in the previous paragraph about the transitions' triangle, the domain identified is "land take".
According to the basic features of the ontological framework, three macro-concepts relevant to the transitions triangle were identified: *land-policies-processes*. Each macro-concept contains a variety of concepts to which a definition and its research source were assigned. Most of the definitions used in the ontology come from the glossary of the EEA [40], EUROSTAT [110], GEMET [111], FAO (UN) [112] and other scientific sources. The result of this first phase is a thesaurus: the first operational output of the process.
The (*ii*) second phase involves the selection of the ontology classes within the thesaurus. In the ontology's terminology, concepts are associated with a class structure: a class is a collection of elements that have the same properties. Similarly, the concepts of an ontology are an abstraction that allows to represent elements of the domain through a set of attributes and properties, so the term class will be used to indicate a concept. A class can be simple if inside it does not contain instances (i.e. objects) or complex if inside it will admit objects. In the analysis of the domain land take, following the identification of the three super classes (*land*, *policies* and *processes*) that represent the main conceptual classes for the representation of the system, meaning that each is not a sub-class of any other class in the ontology. The *land* super class is intended as the physical location of the domain of interest, defined as a specific geographic feature of the earth's surface that includes all of its attributes, including geology, surface deposits, topography, hydrology, soils, flora and fauna, along with the results of past and present human

activity, to the extent that these attributes affect current and future land use. The super class *policies* represent the set of policies that regulate soil and territory, policies that conform to certain principles or directives of a decision-making power: European, national, regional, municipal. The super class Processes concerns the land cover change, both in terms of possible soil degradation and in terms of sustainable soil strategies, i.e. de-sealing and revegetation. According to the three super classes, a total of 343 classes were defined among all the concepts contained in the thesaurus.

The (*iii*) phase 3 involves the building of the class hierarchy that leads to the construction of a taxonomic scheme. A middle-out approach was used, in which central concepts are identified in each super class. This approach allows to bring out thematic fields and improve the modularity and stability of the final result [113]. Through the organization of the hierarchical structure, the super classes present their respective classes which in turn contain subclasses. The classes of the hierarchical structure inherit properties and attributes from the super classes. Fundamental at this point is the definition of the taxonomic relations that define a static model of the domain representation. These can be of a logical, semantic, temporal or physical nature. In the construction of the class hierarchy, the basic taxonomic relation *"is a/part of"* was used. The output of this third phase consists of the taxonomic schema, a set of terms from a controlled vocabulary, organized in a hierarchical structure (Fig. 4).

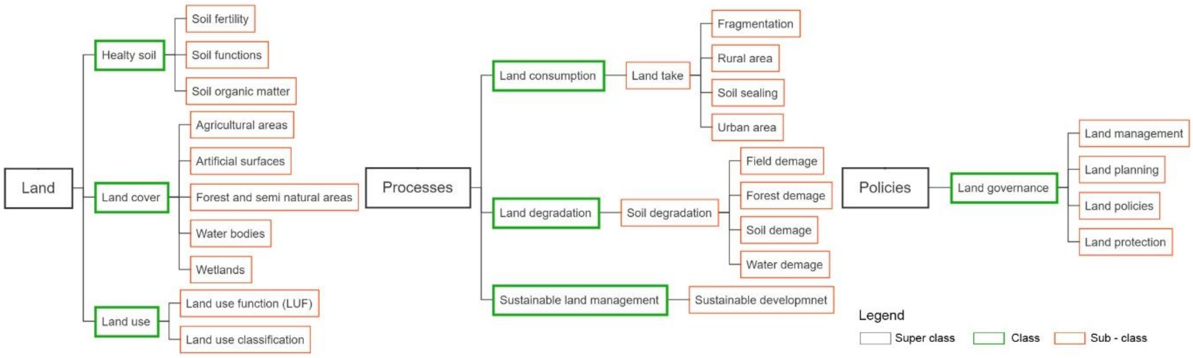


Fig. 4 Taxonomic schema with super-classes, classes and sub-classes.

The (*iv*) fourth and final phase is to identify the relationships between classes that allow for more punctual interactions than the basic taxonomic relationship to be represented. The relationships directly related to the system of the transitions triangle, to the land take domain and to the sub-classes and classes of each super-class have been considered. Specifically, the relationships relate to the actions and four have been identified: *"acts on"*, *"causes a"*, *"produces a"* and *"regulates"*.

These four fundamental operational phases are followed by the ontology populating phase through the instances. This phase is very onerous and, in this research, only a few classes have been populated.

For each instance (individual), a complete description was provided (definition) and the source was specified. For example, the sub-class *"agricultural pollution"*, sub-class of *"land degradation"*, has three individual instances: *"insecticide"*, "*chemical fertilizer"* and *"pesticide"*.

2.3. Ontological modeling, some examples

The modeling of the ontology allows to specify different levels of detail super classes, classes, subclasses, instances and relations and to specify one or more central subjects of the visualization. We report some extrapolations of the entire ontology that for the modest size is not possible to display here in its entirety. In the following extracts the focus is on the relationships and properties related to soil sealing, urban sprawl and urban sprinkling associated with urban sustainability strategies.

Fig. 5 shows the modeling of the three super classes with the related classes and the relationships between them. The *policies* regulate the *processes* that act on the *land*. *Land governance* is a subclass of *policies* that regulate *processes*. *Sustainable land management*, *land degradation* and *land consumption* are part of the *processes*. *Land* has *land cover*, *healthy soil*, and *land use* as subclasses. This schematization allows to have an overview, with reference to land take, of all processes and policies that are related to the phenomenon of anthropic land transformation due to the growth and expansion of urbanized areas (or artificial surfaces), generally at the expense of rural areas, as a result of the implementation of plan design or infrastructure projects.

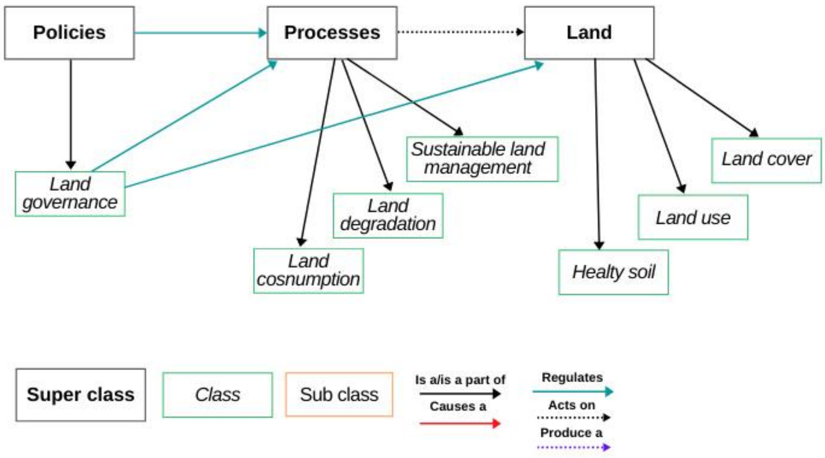


Fig. 5 Example of ontology modelling with the three super-classes and some relations.

In the Fig. 6 the ontology modeling is schematized to bring out the relationships of the ***fragmentation*** sub-class of *land consumption* belonging to the macro-class of *processes*. The primary relationship identified is as follows: *land cover change* and *land use change cause fragmentation* of large patches of the landscape into disjointed, isolated or semi-isolated areas as a result of land use/cover changes. *Fragmentation* has as sub-classes: ***habitat fragmentation*** defined as the process during which a large expansion of habitat is transformed into a series of smaller patches, isolated from each other by a different habitat matrix than the original [114]; ***landscape fragmentation*** defined as the fragmentation of larger areas of natural land cover into isolated smaller areas [115]; ***urban fragmentation*** related to morphological changes in urban areas and their subsequent dispersion in space [116].

Urban sprawl and *urban sprinkling* in turn *produce* fragmentation with negative consequences on the distribution of public services, infrastructure costs, social segregation and landscape transformations, affecting both agriculture and natural soil. Urban sprinkling generates more serious effects than urban sprawl because of its irreversible nature (only possible in the long term) [19] and unsustainable social costs[22]. This uncontrolled land take produces a landscape fragmentation measurable by the reduction of the resilience of habitats, populations, and ecosystems. Fragmentation is therefore a direct consequence of uncontrolled and often unregulated events such as land take.

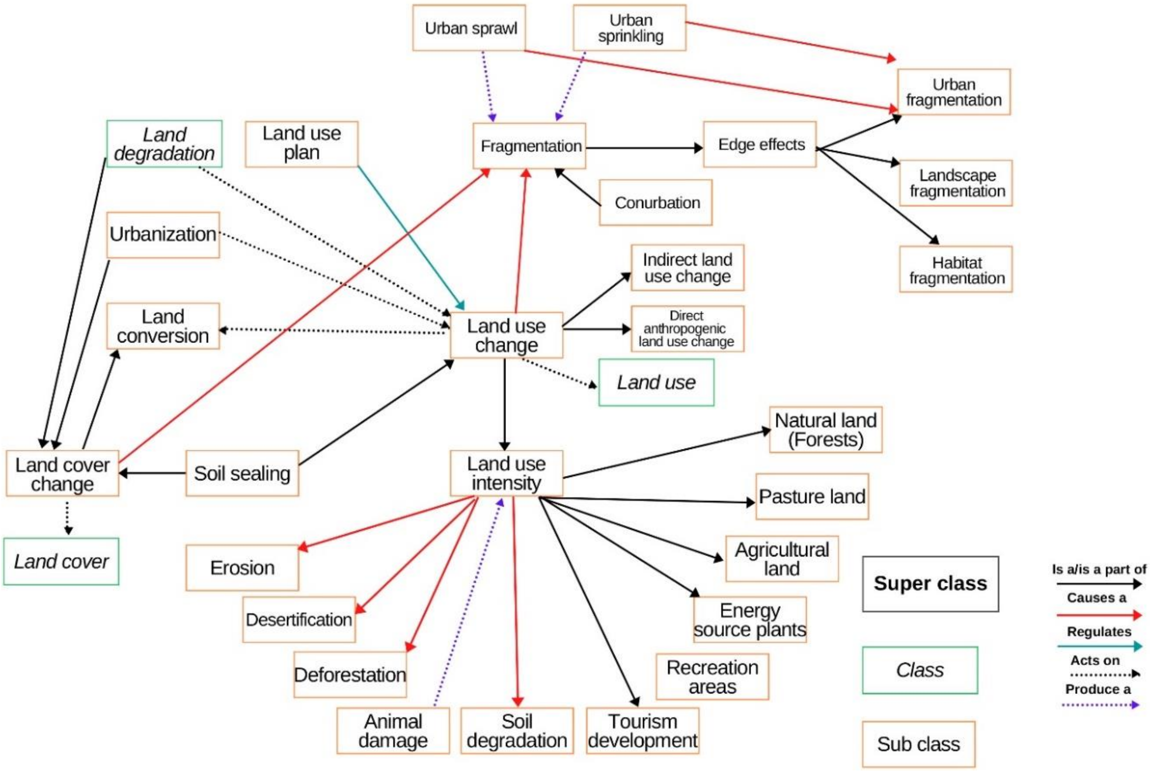


Fig. 6 Example of ontology modelling with reference to the fragmentation and urban sprawl and urban sprinkling dynamics

It emerges, therefore, the need to reorganize the distribution of buildings and their functional areas, to contain sprawl and sprinkling and make development more sustainable in both environmental and socio-economic terms. The processes of de-sprawling and de-sprinkling allow the reorganization of the territory and the limitation of the effects on soil consumption.

In Fig. 7 it is intended to highlight the transition processes that represent the possibility of reversing the process of land consumption: ***de-sprawling*** and ***de-sealing*** (indicated in the transitions triangle Fig. 3 c with dashed lines). The *de-sprawling process* has been considered as a sub-class of *sustainable urban development* which in turn is part of the macro-class *processes*. It represents one of the possible sustainable strategies of urban regeneration able to stop the process of urban sprawl/sprinkling. This process, in the same way as ***de-sprinkling***, would slow down, even interrupt, the phenomena that act and cause further land consumption according to traditional dynamics, in order to avoid further stressing the current conditions. It is an action that should be part of the strategic responsibilities at the regional level [20,46]. The main relationships individuated with the de-sprawling process are as follows:

- *acts on*: *gray land recycling* intended as redevelopment of previously developed land (brownfield) for economic purposes, it affects the re-use of "gray" urban objects: buildings or transportation infrastructure;

- *acts on*: *green land recycling* both ecological upgrading of green urban areas and construction of green sports facilities, and both renaturalization of land (returning to its original state) by removing existing facilities via soil de-impermeabilization;
- *acts on*: ***land densification*** defined as land development that takes place by making maximum use of existing infrastructure instead of building on free land;
- *acts on*: the ***functional urban areas*** (FUA) (sub class of ***urban area***) which consists of the city and the commuting area connected to it. FUA in turn produce land take. Urban sprawl, urban sprinkling and urban shrinking are, in fact, three sub-classes of FUA. They represent three particularly complex processes that cause a land take, an urban fragmentation of the territory and in general produce the degradation of the soil and its progressive sealing.

The *de-sealing* process is a sub-class of *sustainable soil management* of the macro-class *processes*. From the identified relationships it emerges that de-sealing acts on *revegetation* processes, on *strategies to minimize soil sealing*, on European strategies to contain soil consumption (*No net land take by 2050*), on technical guidelines for sustainable soil management which provide for the increase of *soil organic matter* content, and finally, without any doubt, the *de-sealing* process acts on *land take*.

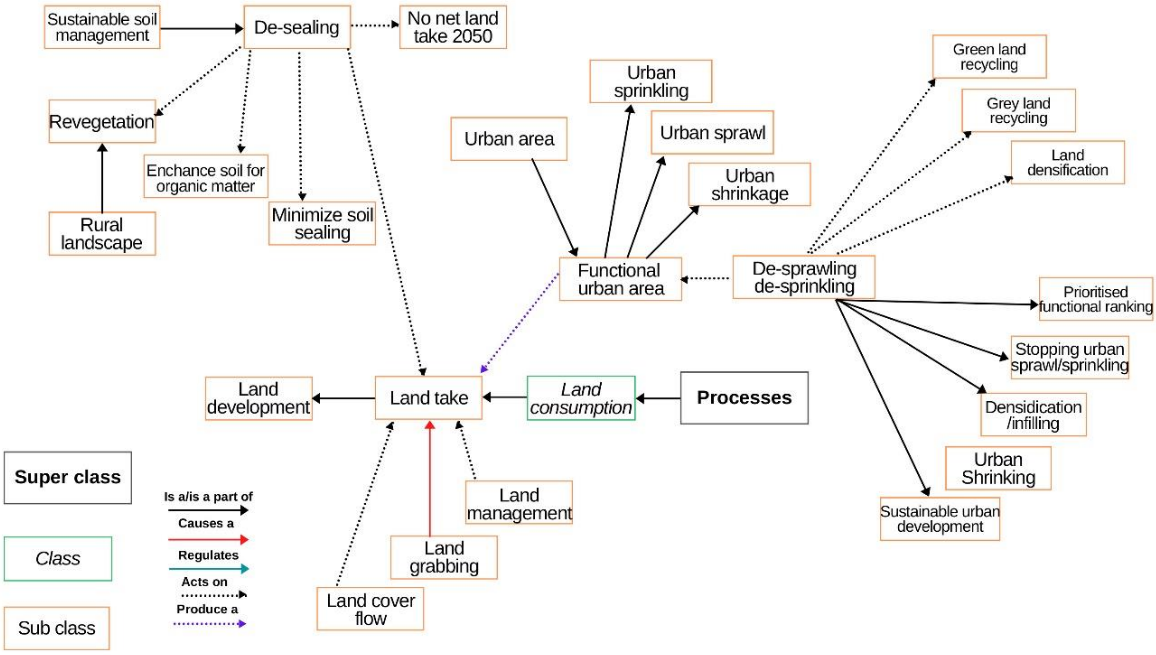


Fig. 7 Example of ontology modelling with reference to the super class processes.

In the last diagram (Fig. 8), we want to highlight the sub-class of *land governance* that is *land management* of the super-class *policies*. Below we report the main relationships identified and that can be read on the graph. *Land management acts on*:

- the *land take* since with the operations of preparation and control for the implementation of plans for the organization of human activities, it disposes and legislates on the transformations of land covers and therefore on the land take;
- *acts on*: *sustainable land management*, class of the processes' macro class. According to the UN definition, the productivity and sustainability of a land-use system are determined by the interaction between land resources, climate and human activities. Especially in the face of

climate change and variability, selecting the right land uses for given biophysical and socioeconomic conditions and implementing sustainable land management are essential to minimize land degradation, rehabilitate degraded lands, ensure sustainable use of land resources, and maximize resilience;

- *acts on*: *ecosystem services* and their regulation; according to the definition Millennium Ecosystem Assessment [117], the class of ecosystem services has as sub-classes: support, regulation, cultural and provisioning services. On ecosystem services act the strategy and guidelines for sustainable development;
- *acts on*: *land degradation* which in turn can be produced by *soil sealing*. Soil management is of critical importance since soil degradation affects soil functions that depend on a range of physical, chemical and biological properties that together determine the essential qualities of the soil.

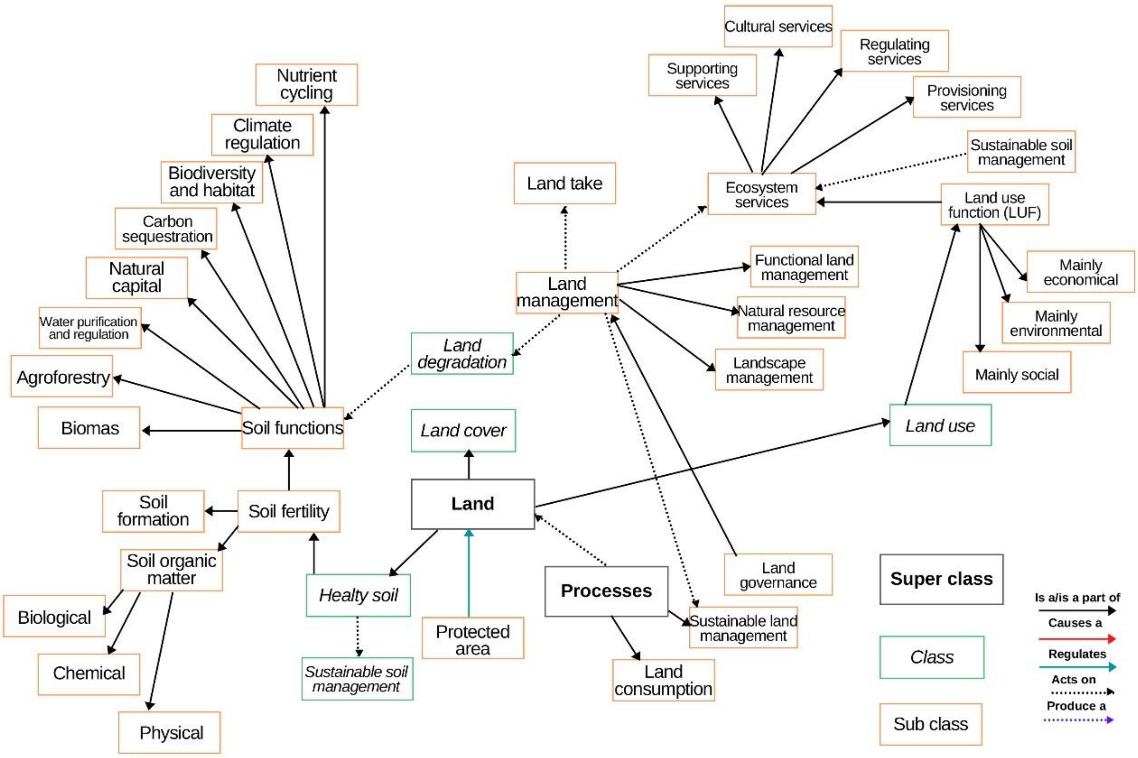


Fig. 8 Example of ontology modelling on the super classes processes and land.

The goal of the ontology on land consumption, consisted in describing, defining and facilitating the understanding of an area of knowledge (land take scope) with the purpose of giving place to an exchange of information between users and experts in the field of the study object. In the objectives proposed, the ontology aims to reduce conceptual and terminological confusions, in order to achieve a shared interpretation, supported by the efforts of the construction of a thesaurus, trying to overcome the heterogeneity and differences of terms from the point of view of multilingualism and semantic interoperability.

From the anthology emerges a strong relationship between the theme of land take and that of urban sprawl and the more recent dynamics of urban sprinkling. As a matter of fact, it is not sufficient to consider only the loss of natural or agricultural areas, but also the distribution of the buildings in the landscape matrix, or rather its spatial component. Nowadays, in big cities as well as in rural areas, there are often cases with a strong fragmentation of the built-up area in which, even if the quantity of land take may not appear worrying, its configuration determines a general decrease of the ecological connectivity, of the landscape quality and the general degradation of soil functions.

Policies, in additional to the role of stopping the phenomena that cause land consumption, should turn their attention towards a sustainable urban development policy in order not to burden further the current conditions. The construction of the thesaurus and all the relationships between the class has allowed to have a clear picture of the dynamics that gravitate around the land take even if there is still much to do. Although few relationships have been identified, it was possible to build and model small anthologies that allow to frame various issues such as those of fragmentation, land degradation and in particular that of urban sprinkling which will be discussed in the next chapters.

3. Urban SPRINKLING: a new perspective of land take

From the previous chapters it has emerged the urgency to address the issue of land take according to different indicators that allow to evaluate it not only in quantitative terms but also on the basis of the shape of urban settlements and their dispersion in the territory. Starting from a brief description of the main urban transformation dynamics, this section aims to analyze land take through an urban dispersion index. The urban sprinkling, a recent dynamic of urban expansion and transformation (different from the more widespread urban sprawl) has been recognized in many western inland areas, especially in Italy. This dynamic is characterized by very low settlement density indexes and involves the fragmentation of the territory into small particles dispersed on the territory producing irreversible damage. The spatial configuration of the Italian settlement pattern at regional and provincial level, was analyzed through a spatio-temporal analysis of the global Moran index and other quantitative variables. The results provide, for each territory, a reading of the main expansion dynamics occurred from the 50s to nowadays: compact city, urban sprawl or urban sprinkling.

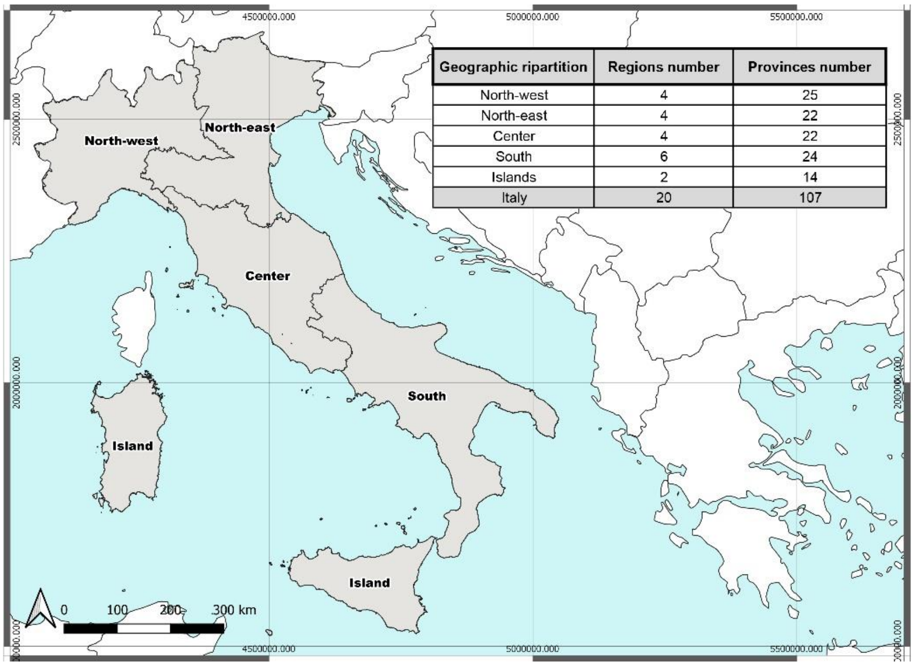
The 2050 targets of zero net land take (EU Environment Action Program to 2020 (7th EAP) [27,50,51] by the European Community are crucial for fragile and critical territories, among which is certainly placed the Italian one [52,118–120]. The definition and implementation of such policies, rules and actions aimed at reducing land take are as urgent as possible. In the last 50 years, land occupation in Europe has become more and more important, leading to the development of low density and fragmented urban settlements. Urban extensions have thus moved away from the more traditional and recognized dynamics of urban expansion, acquiring different forms and very low settlement density rates [32,53,121]. Italy is still far from the European objective "No net land take by 2050" [30], according to the Italian Institute for Environmental Protection and Research (ISPRA), it consumed 48 square kilometers of net land in 2019 [57]. In Italy, since the 50s, the phenomenon of land take has been a consequence of several factors: urbanization, the construction of transport infrastructure including ports, airports and highways, the optimization of industrial and productive systems. After the Second World War (IIWW), population growth and the consequent demand for housing generated a strong urbanization process in the main poles of Italian economic development. Since the early 2000s, the situation has been completely reversed and in most cases the phenomenon of land take is no longer based on the real need for new areas of urban expansion based on effective urban planning tools, but is strongly

correlated to a dispersed demand for new housing in a weak spatial planning system that is unable to drive effective urban development that minimizes speculative real estate initiatives [60,122,123].
The phenomenon is aggravated by a spatial configuration of urban settlements that is fragmented in most cases and at low density. In recent years, in fact, a new form of urban expansion called urban sprinkling has been recognized [33] and characterized by even lower building density indices than urban sprawl and a pulverization of urban settlements on the territory. This phenomenon has been identified in Italy and is precisely representative of some internal western areas that, while recording a declining and/or static demographic variability, have the necessary resources to continue to invest in urbanization processes [124–126].
Many researches have highlighted the critical aspects of cities with low settlement density (sprawl or sprinkling phenomenon), which mainly concern the inefficient use of energy sources and uncontrolled consumption of land [23,24] and the higher economic and social costs [22,127,128]. As demonstrated by Romano et al. [20], urban sprinkling generates effects more serious than urban sprawl due to its irreversibility (possible only in the long-term). This uncontrolled land take generates landscape fragmentation assessable by the reduction in resilience of habitats, populations, and loss of ecosystem services [44,129,130]. The irreversibility of the phenomenon and the limited effectiveness of policies aimed at limiting its future evolution are elements of considerable concern [20].
The high-density city with the more compact spatial configuration (mono-centric development) remains the most sustainable form of development [15,28].
From this section to the following ones, through a series of applications at national and regional level, will be analyzed the transformation dynamics and intensive use of artificial land that could be effective indicators of the quality of settlement processes and could provide information on the impact of protection and exploitation policies in natural and rural areas.

3.1. Analysis of urban dispersion in Italy from the 50s up today

In this section, the dynamics of urban expansion in Italy from the 50s to 2019 will be analyzed in quantitative and morphological terms. The urban dispersion of Italy at provincial and regional level will be evaluated through the Global Moran index and other variables such as the proportion of urban area, the population density and the mean altitude of the analyzed territories. This analysis allows to identify the main transformation dynamics of Italy, i.e., urban sprawl or urban sprinkling, two low-density expansion phenomena characteristic of this country.
The settlement dynamics of the Italian country are not always coupled with a real settlement demand. In fact, if the expansion of urban areas generally goes in parallel with population growth at the global level, it is not exact to formulate hypotheses of correlation between the two phenomena, especially with regard to the Italian and European context where the link between demography and urbanization processes is no more evident and cities have grown even in stable or decreasing demographic conditions [33,131]. These unsustainable urbanization processes have led to an often fragmented settlement structure, deeply affecting the territory and indirectly the quality of life, the landscape and many factors that contribute to increase the impact on climate change issues.

The Fig. 9 shows the geographical partitions in which Italy is divided and for each one is reported in the table the number of regional and provincial territories. The Italian territory is divided into 5 partition with a total of 20 regions and 107 provinces. The provincial territories are then further divided into smaller administrative units: the municipalities (7903 Municipalities [132]), which, with the exception of a few regulations at regional level, are responsible for regulating their urban policies.



Geographic ripartition	Regions number	Provinces number
North-west	4	25
North-east	4	22
Center	4	22
South	6	24
Islands	2	14
Italy	20	107

Fig. 9 Map of Italy with geographical breakdowns and table showing the number of provinces and regions for each of them.

As a matter of fact, since 1942 (urban planning law of 1942 - n.1150) Italy has no longer emanated a national urban law on urban planning and territorial transformations. Starting from the 70s, all legislative activity in the field of territorial governance has been delegated to the Regions. This has led to a high degree of disparity among Italian regions and fragile strategic regulations delegated in many cases to municipalities that are often very small and without the necessary expertise to address the theme [24,60]. Several proposals for laws on land take at national level have been presented, which for now remain in the draft form.

3.1.1. Materials and Methods: dataset building and global Moran's I

To analyze the urban dispersion of the Italian territory, two datasets in raster format were used: one referring to the 50s and the other to the year 2019. The dataset of the 50s comes from previous studies carried out by a group of researchers from the University of L'Aquila [133,134]. The data was obtained in vectorial form according to a non-sampling measurement method in scale 1:20000 using the cartographies of the Italian Military Geographic Institute (IGM). The urbanized surfaces in this dataset are represented by areas covered with buildings of all uses and their ancillary areas such as parking lots, neighborhood streets, storage areas and other artificial areas. The dataset 2019 (in raster format) is the national map of land consumption produced by ISPRA [135] at 10 m resolution based on Sentinel 1 and 2 satellite images of the Copernicus project. The classification of these images by ISPRA is made since 2019 according to three macro categories: (i) permanent land consumption, (ii) reversible land consumption and (iii) other forms of land cover not included in the land consumption. Each one is discretized into other subclasses. In order to make the two data comparable (50's and 2019), the 2019 land consumption raster containing more than one classification level has been transformed into binary raster (0/1). With the value 1 the classes of buildings and industrial complexes included in the permanent land consumption have been classified, while with the value 0 all the rest. Both datasets were finally transformed into binary raster (0 non-urban /1 urban) with 10x10 m resolution.

Among different indices present in the literature for the urban dispersion assessment (indexes of proximity, isolation and shape, landscape metrics and other [8,49,136,137]), in this research the Global Moran index (Moran's *I*) with Queen criteria was used to analyze the morphological configuration of urban settlements from an aggregative point of view. Moran's *I* is a measure of spatial autocorrelation that allows to analyze the shape of spatial patterns [138–140]. It has a range of values between -1 and 1 where: -1 indicates a negative autocorrelation and therefore a dispersed distribution of data, the 0 value indicates no-autocorrelation corresponding to a random distribution and the 1 value indicates a positive autocorrelation that correspond to a clustered distribution. A further subdivision of the value range between 0 and 1 can identify various levels of clustering that can be expressed, analyzing the ones value of the raster, in different patterns of urban dispersion. The maximum value of Moran's *I* (1) corresponds to the most possible compact urban form (theoretically the circular shape); with the decrease of the index, the degree of dispersion increases at the cost of the compactness degree, moving, gradually, from the dynamics of sprawl to that of sprinkling (Moran's *I* very close to 0). The Moran's *I* has therefore been calculated on the value 1 of the urban surface raster. According to Jaeger's definition of "urban sprawl" (see Glossary section) [42], both the urban size and morphology play a fundamental role in the characterization of urban sprawl and urban dispersion. Moran's *I*, which in this case represents the morphological configuration (indicates the intensity of urban sprawl), alone is not sufficient to define the dynamics of transformation and, for this reason, has been evaluated together with the proportion of ones that correspond to the proportion of urban surface (P_u) with respect to a specific reference area. Proportion of urban surface in this case means only the surface occupied by buildings and their areas, without considering the road infrastructure outside the main centers. The urban dispersion has been evaluated by comparing the Moran's I index and the proportion of urban surface referred to all the regional territories. It is important to evaluate the P_u together with the Moran's *I* in order to compare different territories. Shortridge in 2007 [141] highlights the limits of Moran's autocorrelation index for raster class map and shows that in the case of Queen/King contiguity and in the range of positive autocorrelation, the Moran's *I* is little sensitive to the variation of urban proportion in a range of value from 10% to 50%. Therefore, when the P_u of the territories to be anlyzed are less than 50% it is possible to make a comparison of the respective Moran's *I*.

In order to obtain areas with similar and homogeneous behaviour for morphological and demographic characteristics, variables of altimetry and population have been considered and analyzed with a cluster analysis referred to all the Italian provincial territories. The altimetry variable derives from the Digital Terrain Model (DTM) with a resolution of 20 meters (source National Geoportal [142]) from which the average altitude (Alt_{MEAN}) has been derived for any provincial territory. The population variable derives from the census of National Statistical Institute (ISTAT [132]) for the 50's and the year 2019, on the basis of which the population density (D_p) rate was calculated.

The objective of a clustering analysis is to define a grouping of attributes that minimizes the dissimilarity within each cluster. It is important to clarify that clusters are based on the similarity of attributes and do not take into account the contiguity between elements. The characteristic of a cluster is in fact the homogeneity within it and the heterogeneity with respect to the other groups.

From a mathematical point of view the clustering can correspond to any measure of dissimilarity, i.e. a function of overall dispersion that consists in adding the distances between all pairs of observations.

In this research we selected the k-means clustering algorithm [143] which uses squared Euclidean distance as a measure of dissimilarity and, K-means++ [144] as initialization algorithm. K-means++ is based on the square weighting of the distance for the assignment of the first set of cluster centers differently from the more traditional Lloyd initialization algorithm [145] with which the assignment of the first set of cluster centers is obtained in a uniform random way, i.e. each observation has the same probability to be selected.

The analysis was carried out considering as reference surfaces first regional and later provincial territories at Italian national level.

3.2. Results: urban dispersion at regional and provincial level

For all regional and provincial territories, the Moran's *I* has a Z-score greater than 2.58 which corresponds to a high significance of the analysis, i.e. a probability of less than 1% that the clusterized distribution depends on a random choice [140]. All values of the Moran's *I* are greater than 0 and therefore represent a clustered distribution of urban surface that can be divided into various levels of clustering (associated with different levels of urban dispersion). According to Shortridge [141], all the value of P_U at regional level are less than 9% and all values of P_U at provincial level are less than 40%. Fig. 10 shows three examples of different spatial distribution of urbanized surfaces according to the Moran's *I*; it emerges that as the Moran's *I* decreases, the dispersion of the patches of urban surface in the selected boxes increases.

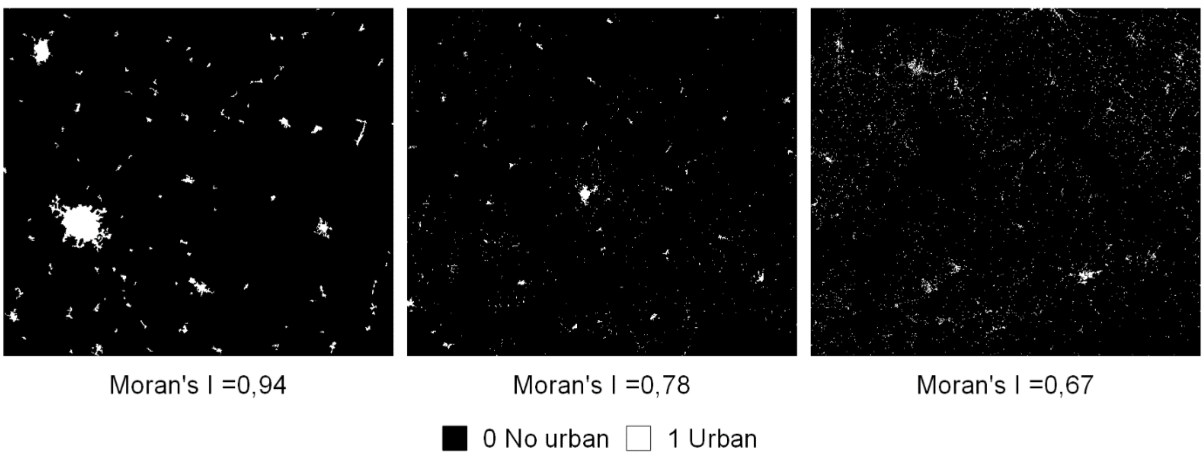


Fig. 10 Different spatial distribution according to the Moran's I; example pf the year 1950.

In the following two sub-sections the results at regional and provincial level are presented. The results at the regional level provide an overall picture of the urban dispersion degree, which will then be deepened with the analysis of other variables and a clustering process at the provincial level.

Urban dispersion at regional level

Table 2 shows the values obtained at regional level for the 50s and 2019 variables: proportion of urban area (P_U), population density (D_p) expressed in inhabitants per square kilometer and the Moran's *I* index calculated with Queen mode. For each region the average altitude (Alt_{MEAN}) has been reported. In the last rows of the table are indicated the same values for the entire Italian territory (Code IT) and the mean, median and the standard deviation values for each variable.

Table 2 Results of P_U and Moran's I at regional level

Code REG	Region	P_U		D_p		Moran's I Queen		Alt_{MEAN}
		50'	*2019*	*50'*	*2019*	*50'*	*2019*	
1	Piedmont	3.49%	5.13%	138.47	171.25	0.899	0.768	677.46
2	Aosta Valley	0.71%	0.95%	28.88	38.55	0.903	0.579	2103.46
3	Lombardy	3.95%	7.82%	275.01	421.46	0.895	0.721	487.72
4	Trentino-South Tyrol	0.90%	1.58%	53.50	78.75	0.810	0.655	1574.14
5	Veneto	3.70%	8.14%	212.41	266.70	0.801	0.700	319.37
6	Friuli Venezia Giulia	4.32%	5.37%	156.37	154.78	0.933	0.690	348.85
7	Liguria	2.34%	4.12%	289.17	286.16	0.906	0.641	517.66
8	Emilia-Romagna	1.51%	5.36%	158.91	198.73	0.942	0.695	286.15
9	Tuscany	0.91%	3.59%	137.50	162.34	0.669	0.666	376.74
10	Umbria	1.86%	2.87%	95.09	104.33	0.808	0.657	458.81
11	Marche	2.11%	4.46%	142.23	162.58	0.727	0.664	389.31
12	Lazio	1.00%	4.65%	194.28	341.89	0.884	0.590	414.71
13	Abruzzo	0.67%	2.85%	118.32	121.51	0.813	0.619	654.98
14	Molise	0.52%	1.69%	91.61	68.82	0.776	0.568	623.47
15	Campania	2.75%	7.37%	319.90	427.02	0.941	0.666	394.10
16	Apulia	1.14%	4.99%	166.55	208.35	0.918	0.637	184.59
17	Basilicata	0.21%	1.28%	62.81	56.33	0.862	0.545	493.38
18	Calabria	0.86%	2.98%	135.63	129.18	0.818	0.609	466.08
19	Sicily	1.30%	4.25%	174.63	194.65	0.859	0.638	394.02
20	Sardinia	0.53%	1.78%	53.05	68.10	0.935	0.627	313.37
IT	Italy	1.83%	4.47%	157.67	200.35	0.870	0.690	
	Mean	1.74%	4.06%	150.21	183.07	0.85	0.65	573.92
	Median	1.22%	4.19%	149.35	162.46	0.87	0.65	436.76
	Standard deviation	1.27%	2.13%	79.37	114.48	0.08	0.05	457.82

The graph in Fig. 11 shows the P_U on the x-axis and the Moran's *I* on the y-axis. The grey indicators refer to the results of the 50's while the blue indicators refer to the results of the year 2019. The labels represent the codes of the regions. Taking as reference the data of the 50s, it is possible to analyze the transformation dynamics occurred in terms of variation in shape and size of settlement patterns. The standard deviation allows to quantify the interval within which the various parameters are distributed and is therefore considered as an error to be associated with the mean value. The high standard deviation values for the P_U show that the distribution of the points (representing the regions) is very far from the P_U mean value. For this reason, the mean value plus once the standard deviation (Mean+StD) was used as a reference point to describe the transformation dynamics linked to the urban dispersion phenomenon. Mean+StD of the P_U and Moran's *I* (red point in Fig. 11) allows the division of the graph into four quadrants identified by dashed lines (from *a* to *d*). The threshold value referred to the 50's has coordinates X: 3.01% and Y:0.93. Analyzing the graph emerges for each quadrant:

- *a*: HIGH Moran's *I* LOW P_U, almost compact urban shape with a low percentage of urban surface, compact and "sustainable" urban expansion;
- *b*: HIGH Moran's *I* HIGH P_U, an almost compact urban shape with a higher percentage of urban surface, urban expansion with an increase in existing area;
- *c*: LOW Moran's *I* HIGH P_U, urban shape tending to dispersion with a high percentage of urban surface that is comparable with urban sprawl dynamic;
- *d*: LOW Moran's I LOW P_U, urban shape tending to dispersion with a very low percentage of urban surface area, decrease of "compactness" of the urban shape that is comparable with the urban sprinkling dynamic.

In the 50's the points are mainly disposed in the upper part of the graph while in 2019 they are all shifted to the lower part of the graph. The P_U of the whole Italian territory (IT) has grown in a high way, i.e. by almost one and a half times (144%) that of the 50s. On the other hand, the Moran's *I* decreased by 21%, indicating that the new urban expansion has occurred in a dispersed manner and far from the existing one.

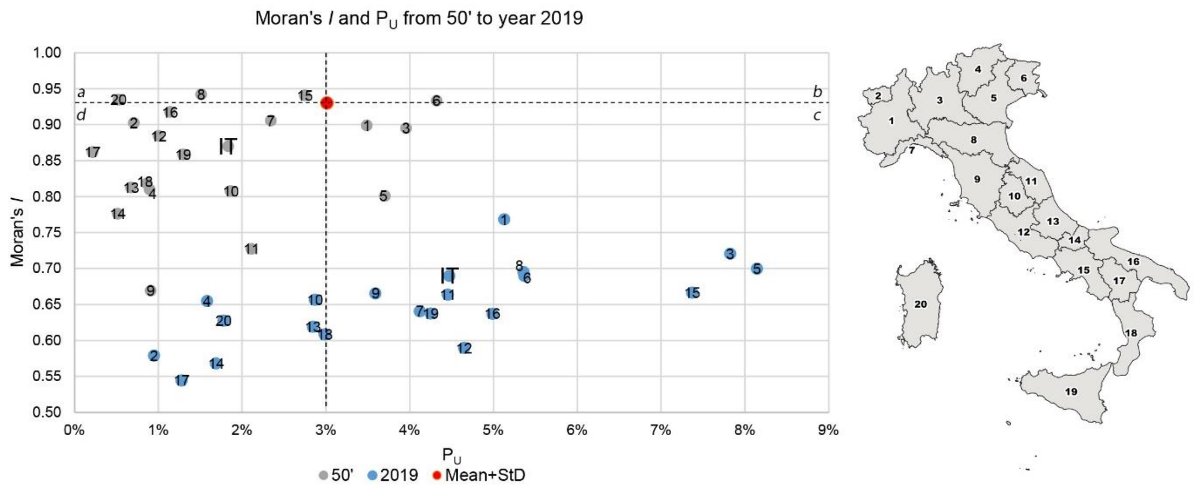


Fig. 11 Graph of the evolution of the Moran's I and P_U between 50' and 2019 at regional level. The map of Italy on the right with the identification of the regions and their respective codes.

All the regions in 2019 are located in the bottom of the graph (Fig. 11), and they are very far from the Mean+StD value identified in the 50s, which shows how the dynamics of urban expansion have occurred in a different way from the urban areas already existent on the territory.

The Basilicata region (code REG 17) has the lowest Moran's *I* (0.55) that related to the P_U describes a very low density and dispersed urban fabric: typical characteristics of urban sprinkling dynamics (quadrant *d*). In this region the 2019 P_U grew about 5 times that of the 50s while the Moran's *I* decreased by 37%. The result is even more relevant if you read it together with the D_p, which in about 70 years has decreased by 10%. Tuscany (code REG 9) is the only region with a stable Moran's *I* (decrease of 1%) compared to a P_U almost tripled from the 50s to 2019. The transformation dynamics were stable and looking at the graph (Fig. 11) we can see that the region moved from quadrant *d* (urban sprinkling) to quadrant *c* (urban sprawl) and this happened in concomitance with a 18% increase of D_p. The Piedmont region (code 1) has in 2019 the highest Moran's *I* (0.77) with a decrease of 15% respect to the 50s. Most of the urban transformations in this region took place in the 50s when the P_U (3.49%) was already very high compared to the Italian P_U of 1.74% and the value of mean plus standard deviation; in 2019 the P_U increased 0.5 times following a dynamic very close to that of urban sprawl (quadrant *c*). Of particular interest are the three regions: Lombardy (code REG 3) Veneto (code REG 5) and Campania (code REG 15) which in 2019 are separated completely from the points of other Italian regions (Fig. 11). In spite of large P_U values (over 7%), the Moran's *I* remains low (below 0.70) reflecting urban transformations dispersed in shape and high in quantity. A more sustainable urban expansion would certainly have seen these three regions move from quadrant *c* to quadrant *b* or better, quadrant *a*.

Urban dispersion at provincial level

Tab i in Appendix represents a collection of all data obtained at provincial level regards P_U, D_p, Moran's *I* and Alt_{MEAN}. The P_U and Moran's *I* data from 50's to 2019 are summarized in the graph in the Fig. 12 in which the four quadrants (from *a* to *d*) are identified according to the Mean+StD values with coordinates X: 5.5% and Y: 0.94. The numbers above the indicators in Fig. 12 represent the codes of the provinces that, due to spatial and data overlap, were not all represented. All points move down the graph in 2019, which means that in all provincial territories the level of urban dispersion increases (Moran's *I* decreases). The Rieti province (code PRO 57) has the lowest Moran's *I* in 2019 (0.50) decreased by 39% compared to the 50s and a low P_U (1.52%) tripled respect to the 50s. An urban settlement that has grown considerably but in a dispersed manner and in conditions of demographic decrease, leading to unsustainable urban development. In the same position is the province of Potenza (code PRO 76) which is part of the Basilicata region (code REG 17) that, compared to a P_U quadrupled since the 50s, the Moran's *I* decreases by 40%.

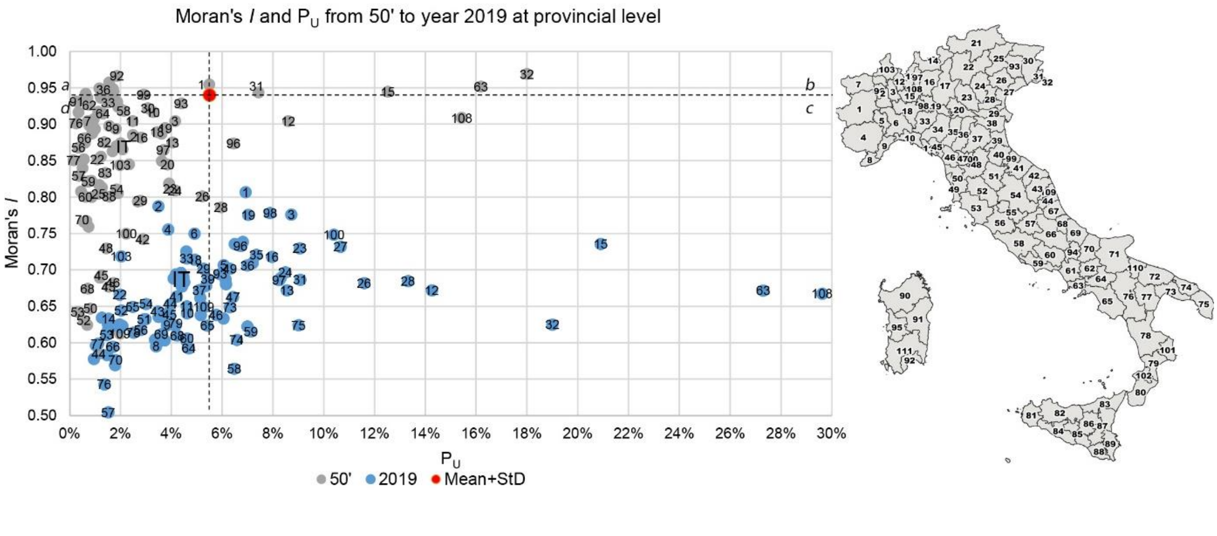


Fig. 12 Graph of the evolution of the Moran's I and P_U between 50' and 2019 at Provincial level. The map of Italy on the right with the identification of the provinces and their respective codes.

The only three provinces that have a positive rate of change (even if very small) in the Moran index are: Pistoia (code PRO 47, code REG 9) and Ascoli Piceno and Fermo (code PRO 44 and 109 and code REG 11). Pistoia province from the 50's to 2019 switches from quadrant *d* to quadrant *c*, its P_U grows three times and the Moran's *I* up 6%. The Moran's *I* is still a dispersed situation, but the increase in the P_U suggests that the new urban expansion took place close to the existing one. Over the 70 years, the provincial territory has changed from a very scattered fabric (comparable to urban sprinkling dynamics) to a less dispersed but not totally compact fabric (comparable to of urban sprawl dynamics).
In the extreme part of the graph are located the provinces with the highest P_U value: Milan (code PRO 15) and Naples (code PRO 63), which have passed from quadrant *c* to quadrant *d* increasing the degree of urban dispersion, and the province of Monza and Brianza (code PRO 108). These provinces are representative of the regions 3 and 15 that emerged in the graph in Fig. 11 in previous sub-section. These values are very far from the mean+StD point and in fact have a very different behaviour from the other provinces: high values of P_U in the year 2019, great decrease of the Moran's *I*, of about 30% in comparison to the 50's value and a very high increase in population density (in Monza and Brianza of about 1.2 times compared to the 50's).
In order to obtain areas with similar and homogeneous behaviours for morphological and demographic characteristics, the Moran's *I* was related, through a K-mean cluster analysis, with P_U and D_p variation rates and Alt_{MEAN}.
Fig. 13 shows the map (on the left) and the bubble plot (on the right) of the cluster analysis with the variables of P_U variation and Moran's *I* variation rate expressed in percentages. With the different colours are identified the 4 clusters and the size of the circles represents the variation of the mean altitude of the provincial territories. The number of clusters (K) was selected using the Elbow Curve method [146] and the validity of the result is given by the ratio between the sum of the squares between the clusters (BSS) and the total sum of the squares (TSS) which for K=4 returns a value of 0.76. The higher the ratio BSS/TSS, the better the score (and thus the quality) because it means that BSS is large and/or WSS is small and this correspond to a non-random clustering.

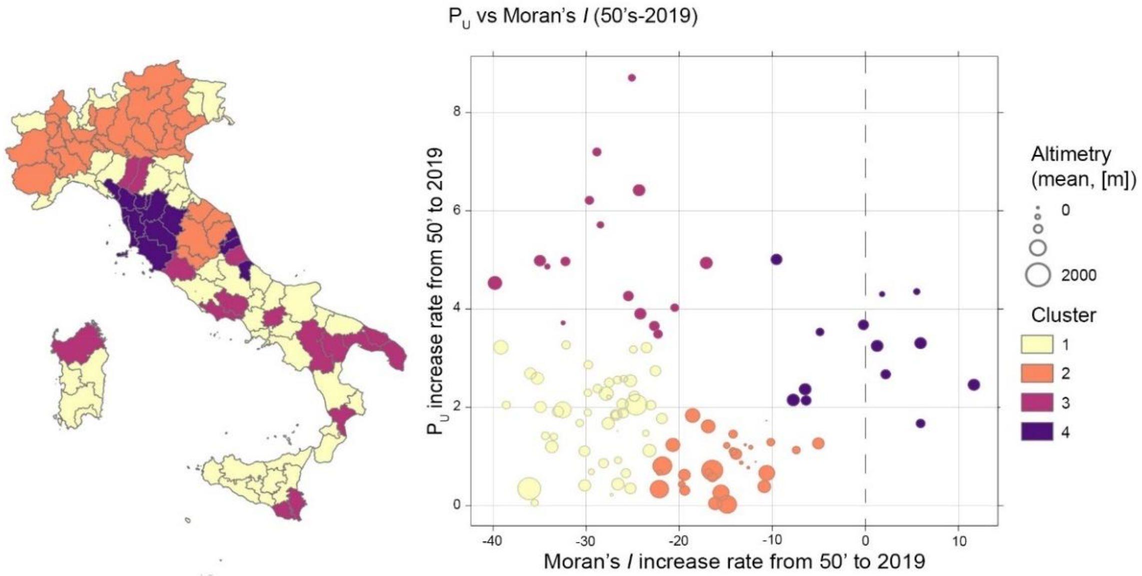


Fig. 13 Map and bubble plot with the cluster obtained from the combination of the variables P_U rate increase and Moran's I rate variation expressed on the graph in points percentage.

The 4 clusters provided a view of the transformation dynamics from the 50s to 2019 and in particular the following conditions are identified:

- Cluster 1: LOW increase of P_U and HIGH decrease of Moran's *I*; 48 provinces are part of this cluster. The provinces of this group are scattered over the territory, their similarity does not depend on belonging to the same regional territory and therefore on a homogeneity of territorial policies. These are territories that, in response to a small increase of P_U have seen a great increase in urban dispersion, not properly calibrating the urban planning choices for new expansions, reaching a not very sustainable urban development.
- Cluster 2: LOW increase of P_U and LOW decrease of Moran's *I*; 30 provinces are part of this cluster. This cluster contains most provinces of northern Italy, which have a P_U already high in the 50s (between 1% and 12%) and whose variation has little impact on the 2019 urban shape, so much so that the urban dispersion increases over time but not excessively.
- Cluster 3: HIGH increase of P_U and HIGH decrease of Moran's *I*; 16 provinces are part of this cluster. It includes many southern provinces and islands that have undergone a great variation of PU and a great increase in urban sprawl leading to unsustainable urban development.
- Cluster 4: HIGH increase of P_U and LOW or NOT SIGNIFICANT variation of Moran's *I*; 13 provinces are part of this cluster. These are expansion dynamics that, excluding the three provinces code PRO: 109, 44 and 68, completely involve the Tuscany region (code REG 9) with its provinces in which a high variation of P_U is followed by a very low variation of the Moran's *I*. In 7 provinces the Moran's *I* increase and this mean that the urban expansion (which in the 2019 grew up to 4 times that of the 50s) has followed rules of compaction and not these of urban dispersion.

Clusters 1 and 2 contain, mainly, the provinces with hilly or mountain morphology, with altimetric elevation greater than 300m (large size of the circles in the Fig. 13). In particular 31 on 48 and 16 on 30 respectively for clusters 1 and 2.

Fig. 14 like the previous graph show the cluster analysis with the variables of D_p increase and Moran's *I* rate increase. In this case for K=4 the ratio BSS/TSS return a value of 0.71. The D_p variable helps to understand whether the expansion dynamics between the 50s and 2019 occurred in the presence of real settlement demand or not. The cluster 1 represents the situation in which the D_p variation decreases and the Moran's *I* has a HIGH declining rate affecting the level of urban dispersion. It mainly includes the provinces of southern Italy where de-population has been high and urban growth has not stopped over the years [19]. The cluster 2 is characterized by an almost stable or with low increase of D_p corresponding to not relevant change in the Moran's *I*. In this cluster there are 31 provinces located mainly in northern and central Italy, historically characterized by a stable or positive population growth [123,133] and a low level of urban dispersion, closer to the compact shape of the city or urban sprawl.

Cluster 3 includes 31 provinces that have undergone dynamics of low population growth and high increase in settlement dispersion. This cluster is not characterized by a uniform geographical location, in fact the provinces are scattered throughout the Italian peninsula and also includes different morphological characteristics (Alt_{MEAN}). In cluster 4, there are the provinces that showed a strong demographic growth (over 50% between the 50's and the year 2019) and a generally high increase in urban dispersion.

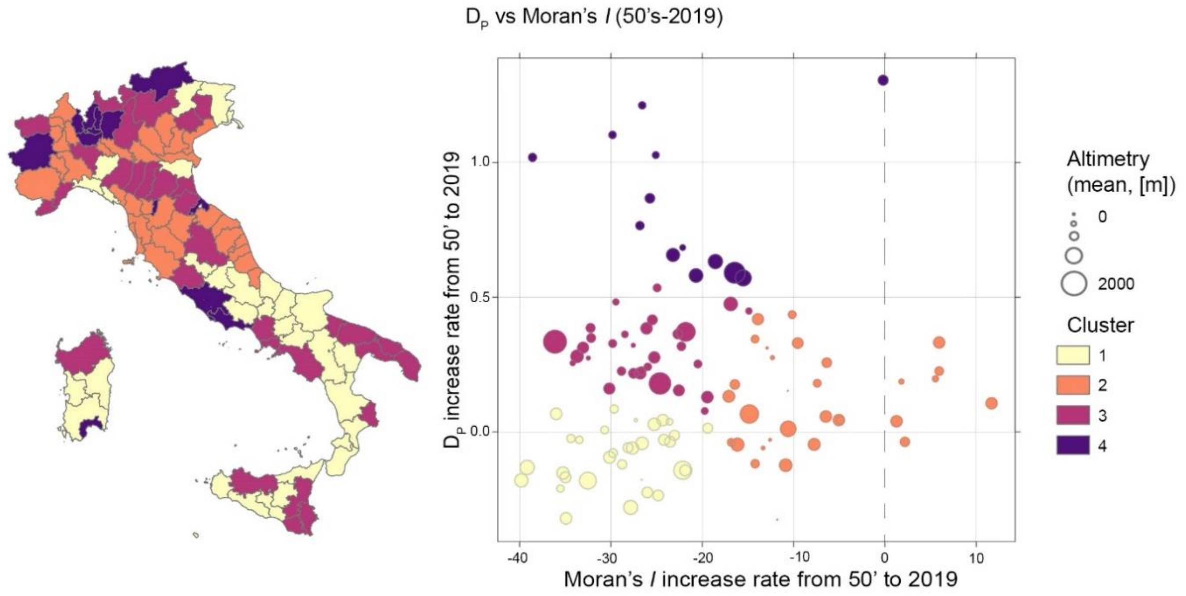


Fig. 14 Map and bubble plot with the cluster obtained from the combination of the variables D_p rate variation and Moran's I rate variation expressed on the graph in points percentage.

Fig. 15 show the cluster analysis with the variables of Alt_{MEAN} and Moran's *I* rate increase. For K=4 the ratio BSS/TSS return a value of 0.73. The size of the circles, in the bubble plot on the right in Fig. 15, represents the P_U (expressed in percentage) at year 2019 at provincial territories. Analyzing cluster 4 it emerges that all the provinces with an average altitude greater than 900 m had a variation of Moran's *I* > -10%. Looking at the size of the indicators shows that the P_U at 2019 is low (between 1% and 6%) this reflects an unsustainable urban expansion where between the 50s and 2019, in the face of a low P_U the expansion of cities has occurred in a dispersed way on the territory.

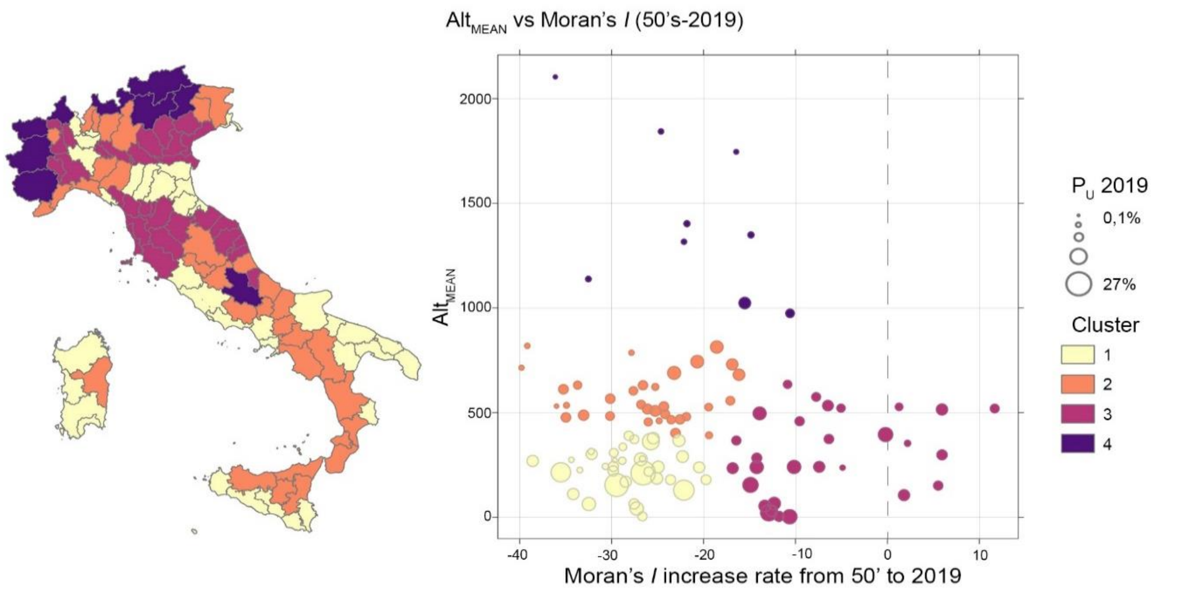


Fig. 15 Map and bubble plot with the cluster obtained from the combination of the variables Alt_{MEAN} expressed in meter and Moran's I rate variation expressed on the graph in points percentage.

The altimetric characteristics, in these cases have affected the shape of the settlements and the dispersion since it is more difficult to maintain a compact shape of the cities in mountainous territories than in territories with more favourable slopes and elevations. The same occurs for cluster 2, which identifies provinces with low P_U common to an average hilly altitude and a large increase in urban dispersion. Cluster 1 includes almost plane provincial territories (Alt_{MEAN} less than 400m) with a large increase in urban dispersion in highly built-up areas (P_U 2019 between 2% and 29%). Finally, cluster 3 is representative of those territories that have undergone a low or insignificant change in the Moran's *I* with a Alt_{MEAN} between 0 and 500 meters.

Fig. 16 shows the cluster map obtained considering: P_U, D_p and Moran's *I* variation from 50's to the year 2019. For K=4 the ratio BSS/TSS return a value of 0.59. The variable concerning altimetry was not considered because it was not expected a result influenced by the morphological conditions that certainly have a fundamental but not prevailing role. The graphs on the right in Fig. 16 show, for each variable, the gamma of values in which the provinces have been clustered. Cluster 1 groups all the provincial territories with a variation of population density almost stationary or slightly decreasing in some cases and a great increase of dispersion related to a not high variation of P_U compared to the 50s.

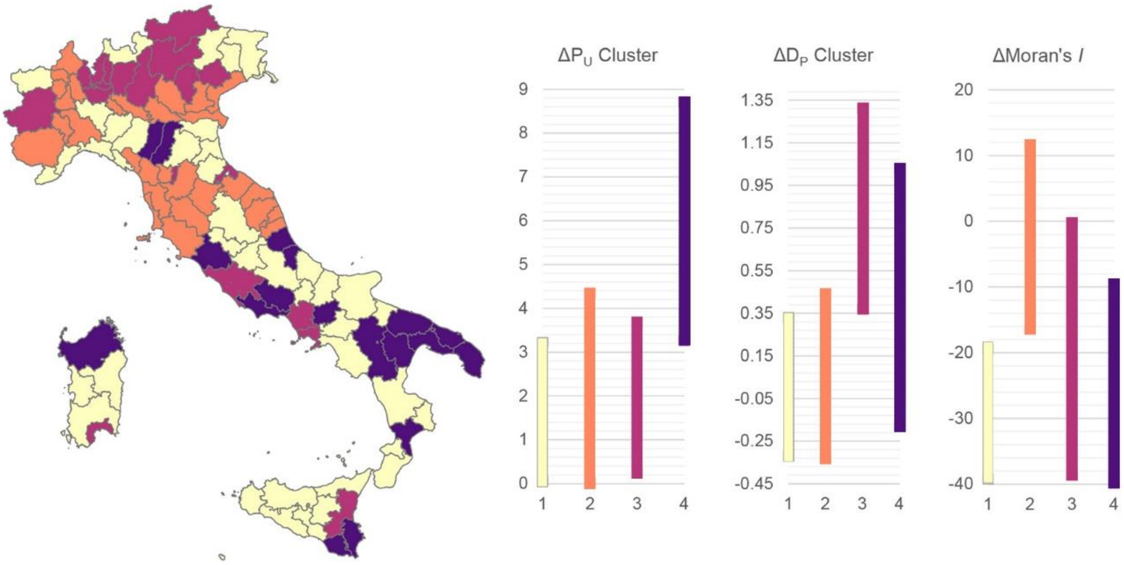


Fig. 16 Map and summary table with the cluster obtained from the combination of the variables P_U rate increase, Dp rate variation, Alt_{MEAN} and Moran's I rate variation.

Cluster 2 contains the provinces with a stationary D_p over time or with a positive demographic rate, a high variation of P_U with a small urban dispersion compared to the 50s. In this cluster the Moran's *I* in some cases increases, leading to a decrease in the dispersed urban settlement configuration. Cluster 3 groups the provinces with an increase in D_p and a small variation in P_U under conditions of high urban dispersion. Cluster 4 groups all the provinces with a very high growth of P_U (up to almost 9 times that of the 50s - the case of the province of Latina) associated with a high increase in urban dispersion and a variation in population density that in some cases decreases and in others increases. The expansion dynamics in these provinces are closer to those of urban sprinkling since large variations in P_U have led to a huge increase in urban dispersion.

3.3. Discussion: Is the spatial configuration of Italian urban settlements dispersed?

With some exceptions, all provincial territories have increased urban dispersion from the 50s to 2019, in some cases very marked and in combination with a not very large urban surface. So much so that in some cases it can be considered urban expansion not justified by real demand.

The Tuscany region with all its provinces, shows a different behavior from the other territories emerging in each clustering for small variations (in many cases positive rates) of the Moran's *I* combined with a high increase of P_U and an almost stationary demographic rate. This means that the urban expansion has taken place more in accordance with the compaction dynamics. This substantial difference with the rest of Italy certainly derives partially from the fact that the Tuscany region was the first in Italy to implement a Regional reform Law in 1995 (LR n. 5 of 16 January 1995) [60].

All the regions of southern Italy and the islands belong to clusters 1 and 2 of the analysis in the Fig. 16 and are characterized by a very high urban dispersion. This is in line with an old regional spatial planning, defined *"Vintage Urban Planning"* by Romano et., al [60] and "*Ghost Planning"* by Scorza et., al [24]. In fact, some of these territories have no urban planning plans and this could only negatively influence the shape of the cities and their governance with inevitable impacts on social, economic and environmental factors. The Basilicata region (Code REG 17) emerges as the region with the highest degree of dispersion which is then reflected in its provincial territory of Potenza (Code PRO 76) which is second only to Rieti (Code PRO 57) for dispersion index in absolute value. Potenza province remains in first position if we consider the rate of variation of the Moran index from the 50s to 2019 showing an expansion dynamic according to urban sprinkling. In the same region, the territory of the province of Matera (Code PRO 77) differs from this behavior showing a high level (but not very high) of urban dispersion but, unlike the province of Potenza, in conditions of positive demographic rate and with a variation of PU bigger than the other one. This also depends on the different morphology of the two territories: the first mountainous and the second hilly or flat.

The employment of the Moran's *I* to detect the morphological configuration of a territory cannot be considered exhaustive for the quantification of land take and fragmentation. In fact, the evaluation made in this research strongly depends on the initial condition of the territories in 1950. However, the Moran's *I* associated with population density and urban area proportion provides a clear picture of the main dynamics of sprawl or sprinkling transformation identified in the graphs in Fig. 11 and Fig. 12. This allows to quantify the land take by applying different indices. With reference to the Fig. 11 it would be impossible to quantify the land take in the Veneto, Campania and Lombardy regions with the sprinkling index - positioned in quadrant *c*- which vice versa can be used for the Basilicata region - positioned in quadrant *d*.

In conclusion, in response to the question posed in the title of the paragraph -*"Is the spatial configuration of Italian urban settlements dispersed?"* - the results show that low-density dispersed urban development, called "sprawl" or "sprinkling", is an alternative configuration that best expresses the structure of much of the Italian urban system and is becoming progressively more significant. In fact, the 63% of the territorial provinces in 2019 is positioned in quadrant d corresponding to urban sprinkling phenomena. The remaining part is in the sprawl quadrant (*c*). Two dispersed and unsustainable forms of urban expansion. Therefore, the answer is: YES, the spatial configuration of Italian urban settlement is dispersed.

4. Spatial indicators to assess the dimensions of fragmentation in the Basilicata Region

Starting from the results of the previous section in which the Basilicata region has the lowest Moran index and therefore the highest degree of urban dispersion coupled with a low percentage of urban area in 2019, in this section we will analyze the phenomenon of urban sprinkling and the fragmentation dimension in the case study of the Basilicata region. Through a spatio-temporal analysis various component of the settlement system have been analyzed including buildings, renewable energy plants, hydrocarbon wells, road infrastructure and more in general all the land cover classes. The fragmentation dimension was analyzed by: sprinkling index, infrastructural fragmentation index and diversity indexes. The results show a fragmented landscape not only due to the traditional expansion of the city caused by the construction of new buildings, but, especially in the last decade, by the unregulated installation on the territory of renewable energy plants with the consequent construction of additional road infrastructure in a territorial context of high landscape value and with generally negative demographic rates.

This section presents some analytic applications for the time series investigation of different settlement system components at the regional scale to discuss the relation between urban expansion and demographic trends, to quantify the land take and to analyze the different fragmentation dimension.

All territorial transformations involving the increase of soil sealing and, more generally, transitions from natural and semi-natural land to artificial land are analyzed. These transformations have often occurred in Italy in an uncontrolled manner generating a fragmentation of the natural and artificial landscape often characterized by particularly low-density indices such as urban sprinkling. The fragmentation of artificial landscape involves the transformation of large portions of natural habitats into smaller ones (fragments) that tend to be isolated from the original [36,147]. In this specific case, the fragmentation process is linked to the morphological changes of artificial areas and their consequent dispersion in space [116]. The fragmentation is a direct consequence of uncontrolled and unregulated land take. Frequently, this phenomenon is not correlated with housing demand and affects segments of territories that are not suitable for transformation, such as hydrogeological risk areas and zones protected by specific regulations such as NATURA2000 network sites [21].

A common practice in several territories is to build new residential neighbourhoods, abandoning existing ones, rather than developing a new process or carrying out urban regeneration. The first option aims to create a compact urban structure and to preserve the natural and semi-natural uses of the territory [16]; the second one realizes a fragmented urban structure with negative consequences on the distribution of public services, infrastructure costs, social segregation and landscape changes, affecting both agricultural and natural soil [22,128,148]. In Europe, at regional scale, ongoing urban development trends have led to the formation of medium-small urban centers, geographically decentralized from the main urban poles and dispersed in the rural areas [46,149].

The rural landscape is the main area where the impact of urban sprinkling phenomena generates problems, fragmenting the territory in many points, often distant from each other, that struggle to be connected with the main service centers [21,44]. In fact, the landscape fragmentation process has two main components: the disappearance of natural environments and the reduction of their surface area, and the progressive isolation and redistribution of residual environments in rural space.

These processes depend on the ever-increasing demand for new urban spaces related to different uses (residential, services, leisure, productive, etc.) as a consequence of traditional policies that prefer urban expansion to the reuse or restructuring of existing urban areas no longer adapted to contemporary standards. In recent years, territorial transformations linked to traditional settlement components have been associated, in particular contexts such as the Basilicata region, with new needs for territorial transformation. As a matter of fact, following the global challenges on climate change and the related framework of international agreements on the reduction of CO2 emissions, a local policy has been promoted on different scales. Renewable Energy Sources (RES) represent an important component of the package of solutions adopted by public and private operators to address global climate change issues, guiding the development of the territory towards low carbon economy and sustainability principles [77,150]. If we focus on RES installations as a new component of land settlement and, therefore, compare its resulting anthropogenic pressure with the metrics already adopted to measure urban expansion, we clearly see how RES development should be considered as a critical issue for effective urban and land use planning. In fact, the installation and operation of RES represents a significant land transformation. It produces effects on several territorial matrices: land use change, land take, fragmentation of natural habitats with elimination of existing vegetation, visual impact on landscape components, change of microclimate, and brightness from direct sunlight reflection (for solar systems) [77,150–153].

The analysis of urban fragmentation represents one of the main components of research on land take [34,154]. A key focus regarding the spatial assessment of urban fragmentation is the application of spatial analysis techniques and indexes that allow the semi-automatic interpretation of available data on the urban fabric. At regional scale, sprinkling indices represent a robust indicator to detect and classify urban dispersion phenomena according to the sprawl model [9,155–157], which has been used to characterize trends in European urban development. Among the main information provided by this urban development model, it is possible to recognize the de-structuring of settlement fabric, urban fragmentation, and natural landscape degradation.

In this section the following components of the settlement system: buildings (residential, industrial and other uses), renewable energy source including solar system and wind power plants, hydrocarbons wells and road infrastructure, will be analyzed spatially and temporally (from the 50s to nowadays) in the context of Basilicata region. The fragmentation of the natural landscape generated by this component will be evaluated through: the sprinkling index (SPX) [19] to analyze changes in the fragmentation level of all settlement system components at two different scales: territorial (with a resolution of 1 square kilometre) and municipal; Infrastructural fragmentation index (IFI) for roads and landscape diversity indices for all the landscape.

A fundamental objective of this chapter is to demonstrate the extent of impacts resulting from unregulated management of all these components of the settlement system at the level of territorial governance. The new transformations (such are those related to RES plants) are a consequence of the development policies of the energy sector and lead to landscape fragmentation, fragmentation of human settlements and generalized landscape impacts. The Basilicata region, due to its low population density outlines a useful case for analysing the degree of urban fragmentation generated by uncontrolled expansion of all the component of settlement system.

4.1. Low settlement density, demographic decrease and legislative weakness.

The Basilicata region, in southern Italy, has an area of 10,000 square km and a predominantly mountainous territorial morphology. The highest peaks reach 2000 meters and the percentage of mountainous territory is 46.8% (altitude over 700 m above sea level).

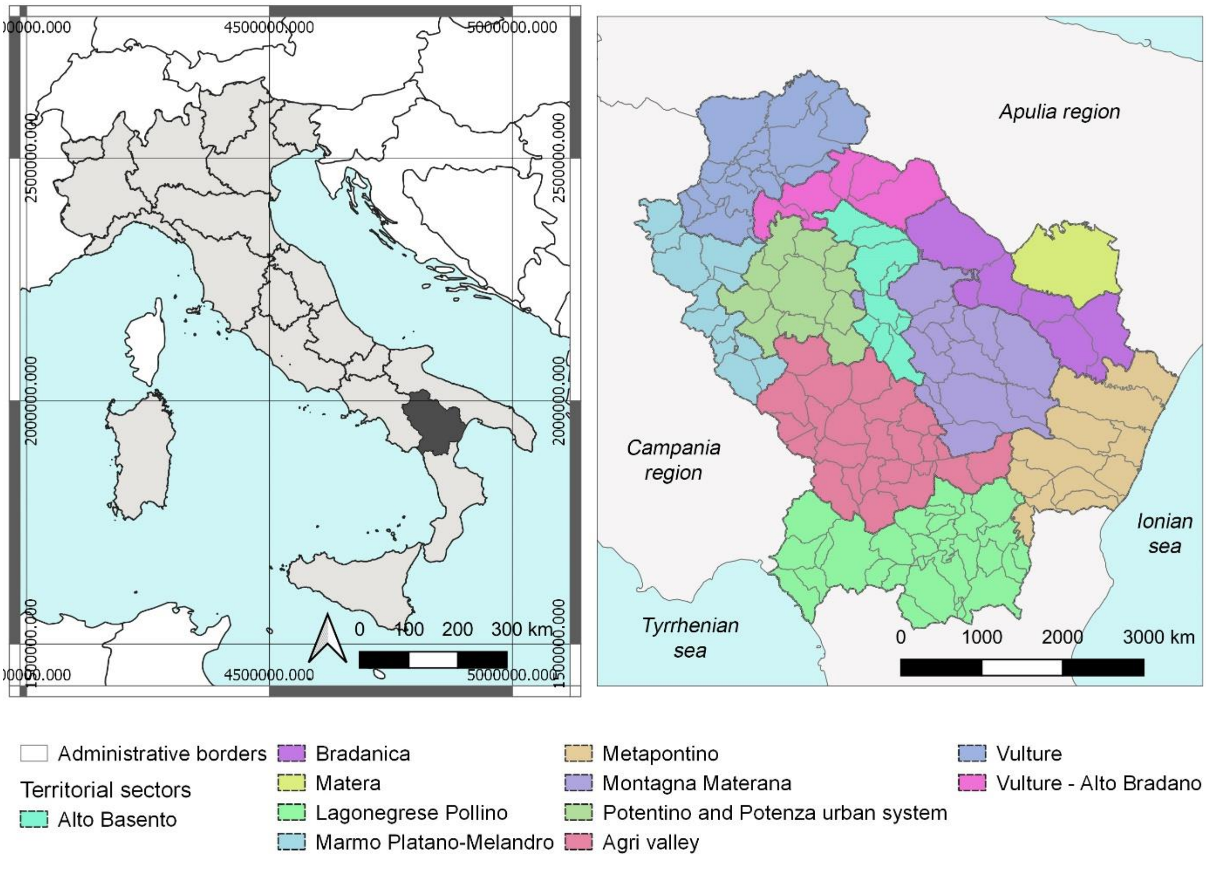


Fig. 17 Geographical overview. On the left the map of Italy with the distinction of the Basilicata region. On the right the Basilicata region with the identification of the territorial sectors and all the municipalities.

The remaining 45.1% of the territory is hilly and only 8% is plain. The region has an abundance of natural environments and a variety of protected areas demonstrated by the presence of two national parks, the

Lucano-Val d'Agri-Lagonegrese Apennines national park and the *Pollino* national park - which with its 1900 square km is the largest national park in Italy - and 58 sites belonging to the Natura 2000 Network, covering about 20% of the regional territory. This paragraph aims to describe the study area (Fig. 17) according to three subsections: the first describes the relationship between the more traditional land take, that is, that related to the transformation of natural soils for the construction of buildings with different uses, and the demographic trend; the second describes the land take related to new components of the settlement system emerging from the new needs related to the renewable and fossil energy sector; the third describes the legislative weakness in which these transformations have occurred.

Land take and demographic trend

The population of Basilicata represents the 0.9% of the total Italian population and 2.7% of the inhabitants of Southern Italy. With 56 inhabitants per square km is the second-last Italian region, followed only by the mountain region of Valle d'Aosta with 39 inhabitants per square km (data from the 15th national census of the National Institute of Statistics - ISTAT - 2011 [132]). The resident population amounts to 567,000 inhabitants, distributed between the two provincial territories of Potenza (368,251 inhabitants) and Matera (198,867 inhabitants) for a total of 131 municipalities.

Table 3 shows that the region is undergoing a decoupling trend [158,159] between the demographic rate that has been negative since the 1980s, and the development of the urban settlement represented by the number of residential buildings, which constantly increase. This is also highlighted by the sprawl index (I_S), which measures the increase in the built-up area in accordance to population growth [160]. This returns values of 5.04 for the entire regional territory and values of 4.71 and 6.13 respectively for the provincial capitals of Potenza and Matera. At regional level, therefore, according to the I_S, the area built between 1950 and 2018 is proportionally higher than the demographic variation that is either stable or decreasing (see: A.1Sprawl index in Appendix).

Table 3. Comparison between settlement evolution concerning the number of residential buildings and population growth from 1950 to 2018.

Year	Population [n Inhabitants]	Increase rate [%]	Residential buildings [n]	Increase rate [%]
1950	627,586	nd[1]	117,687	nd[1]
1989	610,186	-2.7	238,603	102.7
1998	597,468	-2.1	269,019	12.7
2006	591,338	-1.0	285,072	6.0
2013	578,391	-2.2	297,810	4.5
2018	567,118	-1.9	302,010	1.4

[1] nd: no data available.

The sprawl index indicates a dynamic misalignment between population growth and expansion of artificial areas without providing information on the forms of urbanization (spatio-morphological configuration). Although the region is characterized by low settlement density and a predominantly rural environment, it is not immune to land consumption. According to the annual report of the Italian Institute for Environmental Protection and Research (ISPRA), in 2019, a percentage of soil consumed in the Basilicata is 3.15% of the regional area [57]. This data does not appear so serious until it is considered together with the population. In fact, the per capita land consumption between 2018 and 2019 has increased by 1.6 sqm per inhabitant, twice the national average of 0.86 sqm per inhabitant. This land consumption with consequent expansion of urban and rural areas has taken place according to urban transformation dynamics that follow the standards of urban sprinkling. This phenomenon is characteristic of areas with low settlement density, with the expansion of small urban agglomerations far from the existing ones and scattered on the territory without following specific planning rules.

Land take related to new settlement system components

Since the 50s in the Basilicata region, the major urban transformation dynamics have occurred driven by both the demographic increase and the consequent need for housing, and by the general economic growth that led to the establishment of industrial areas and production centers. Soil consumption in this territory, unlike in other regions, does not seem to be linked only to settlement needs [161] but other components related to the energy sector - that has impact on land consumption, ecosystem services, landscape, rural areas and cultural heritage [162–164] - come under discussion.

A peculiar, and more ancient, component of energy settlement is that of oil and gas extraction (wells) and processing (oil industries). In Basilicata, the first drilling for study purposes was carried out in the 1940s in the territory of the Agri Valley, and was almost completely interrupted during the Second World War. From the post-war period onwards, drilling activity has increased in the territory of Matera, along the middle and lower Basento Valley, as well as in the Agri Valley and in the Vulture Alto-Bradano. The Agri Valley hydrocarbon field is currently recognized as the largest onshore field in Europe with a daily production of over 82600 barrels of oil and almost 4 million m3 of gas [165]. In addition to inspection, monitoring, extraction and re-injection wells, there are also two hydrocarbon processing centers, one has been operational since 2001 and the other is still waiting to be started. They cover a total area of over 500 hectares and are expected to increase domestic oil production by 50% [166]. In total there are 120 hydrocarbon wells in the Basilicata region.

Since the early 2000s, with the development of technology for the exploitation of renewable resources for energy production, a significant increase in RES plants has occurred. According to the national Energy Services Provider (GSE [167]), Basilicata is the Italian region with the highest percentage of wind turbines on the national territory (25%), followed by the neighbouring Apulia region (21%). Although is the first region in Italy for number of wind turbine, the percentage of installed power is very low. The areas considered most suitable for the location of wind turbines are those in the north of the region, specifically in the Vulture Alto-Bradano area, where in fact the largest number of wind turbines is concentrated. The regional landscape has been intensively modified by the infrastructure for the production of renewable energy. In the last 5 years, regional wind plants have increased by more than 223% in terms of number of turbines, thus representing more than 1100 MW of installed power. Moreover, thanks to the presence of numerous areas favourably exposed to light, compared to the central and northern regions of Italy, many solar parks have been installed. These, while not generating direct land consumption, involve the construction of additional infrastructural facilities and, in any case, the impossibility for the natural or semi-natural soil to perform its own function.

Fig. 18 shows for all the Italian regions, the percentages of power output produced and number of wind turbines installed and fully emerges the intensity and the diffusion of the transformation dynamics linked to the phenomenon of RES in the Basilicata region. While for the other regions the percentage of wind turbine and the power generated are similar, for the study area this difference is relevant. It is evident how in the greater part of the Italian territory the power produced is bigger than the number of turbines, while in the regions of Basilicata and Tuscany the opposite occurs.

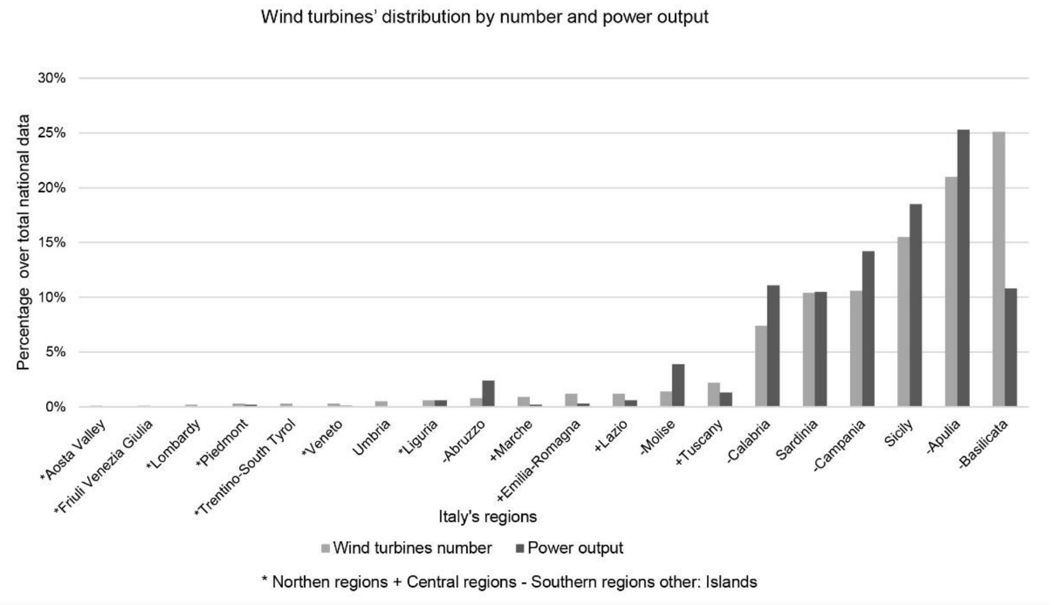


Fig. 18 Wind turbines' distribution by number and power output (in percentage) for each region of Italian territory. Chart elaborated on GSE data [167].

The disparity in distribution between the Northern and Southern regions is evident both in terms of power produced and the number of wind turbines installed. The southern regions and islands, positioned to the extreme right of the graph (Campania, Basilicata, Apulia, Calabria and Sardinia and Sicily) are those with the highest percentage classes.

Legislative weakness

The comparison between the expansion of the artificial areas classified by macro components of the settlement system and the demographic trend from 1940 to 2018 for the whole territory of the Basilicata region, is represented by the graph in the Fig. 19.The main vertical axis shows the data of the artificial surfaces (ha) expressed in base-10 logarithmic scale, while the secondary vertical axis shows the resident population expressed in number of inhabitants. The differences between the anthropic components and the demographic trend are evident: the first all have a positive slope line while the population growth curve shows a fluctuating trend. As a matter of fact, the demographic trend has a positive trend until 1962, then decreases until 1972, is stable until 1992 and decreases until today.

The expansion of urban areas following the construction of buildings was divided into two main phases: the first (1950-1990) due to a real residential need and characterized by the expansion of existing urban aggregates; the second (from 1990 onwards) characterized by prevailing peri-urban and rural transformations (for mainly residential use) with consequent increase in territorial fragmentation.

Together with the classic components of the settlement system (residential and industrial buildings), hydrocarbon production wells have seen a continuous increase since the 1950s and from 2008 to 2018 there has been a marked increase in RES installation.

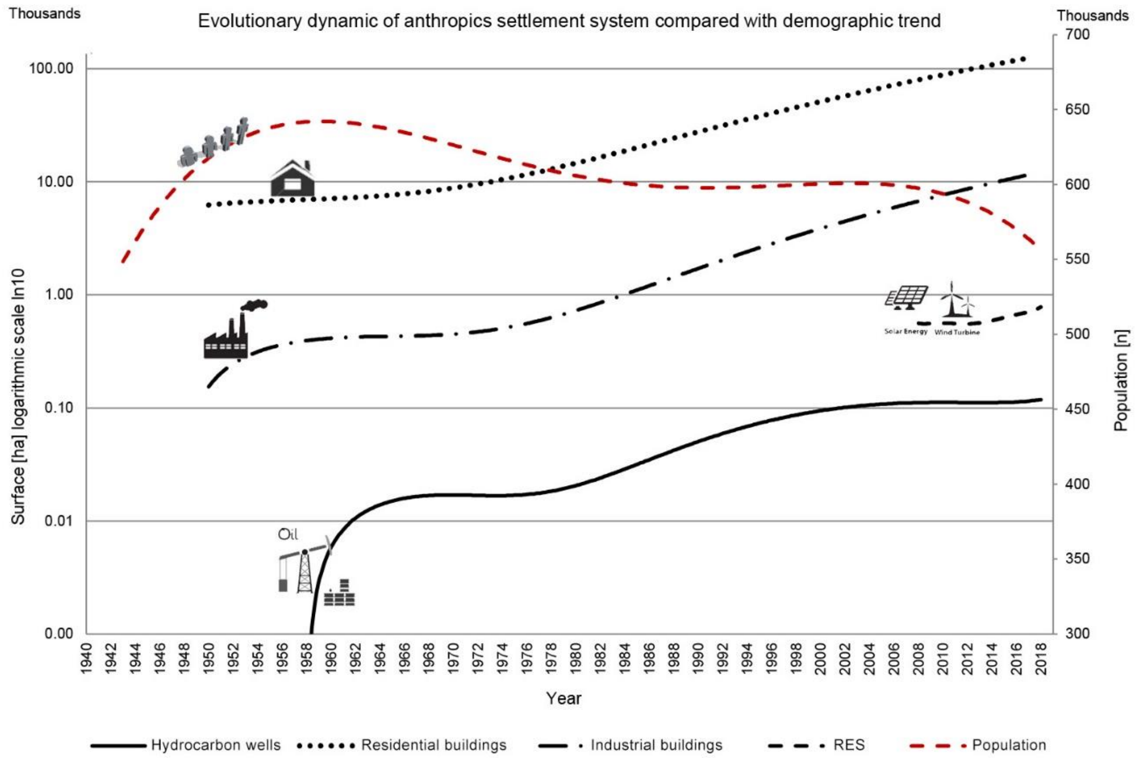


Fig. 19 Evolutionary dynamic graph of the anthropic settlement system components compared with demographic trend in Basilicata region.

Although the main Italian national law on urban planning (n. 1150/1942) dates back to 1942, the Basilicata regional legislative system, on its side, is quite obsolete. Significant delays in the implementation of a structured multiscale planning system have occurred. The region approved its first territorial government law only in 1999 and since then this law has not been fully implemented at regional and municipal level. Before 1968, no municipality had an approved urban planning plan, between 1968 and 1978 only 15 municipalities had a plan, and in 1985 only 26 municipalities had approved a plan [168]. This means that during the period of greatest expansion only a few municipalities have managed the phenomenon of urban growth with ad hoc regulation; for the other municipalities the expansion took place without any plan. In fact, the high degree of fragmentation generated by urban expansion between 1950 and 1989 was not managed with adequate planning tools and was generally facilitated as a driver of economic growth (building sector industry is a major pillar of the Italian economy). At that time, sustainability targets for landscape protection and natural land use were not included as primary objectives at all.

The transformations of the territory due to the new settlement system components regarding the exploitation of fossil resources and the progressive spread of wind and solar energy certainly depend on a complex system of European, national and regional energy policies that have generated significant public and private investments. These processes have taken place in a weak regulatory framework of regional and urban planning laws (Regional Urban Planning Law of Basilicata Region 23/1999) that have not been able to manage such complex and rapidly evolving development scenarios. It is also significant that the impulse given by technologies for the energy production from renewable sources in recent decades has not had uniform effects across the whole Italian territory. According to GSE [167], in 2018 the wind turbines installed in the Basilicata region correspond to a quarter of the entire Italian wind park. The explanation lies in the policies, both financial and administrative, that the Basilicata Region has implemented to increase the percentage of energy produced from renewable sources. Funding and economic incentives have in fact been provided by the Basilicata Region that, within the European Regional Development Fund (ERDF) and the Rural Development Programme (EAFRD), has financed RES plants to support different types of beneficiaries (private citizens, small and medium enterprises, local authorities and administrations) and, therefore, different types of wind turbines. From the administrative point of view, the instrument used to promote the development of RES is the simplified authorization procedure. According to the Plan of Regional Environmental Energy Policy (PIEAR) [169], projects involving turbines with a power less than 1 MW and a number of wind generators not exceeding 5, do not follow the procedure provided at national level but can be authorized only after the Certified Start of Activity Notification (SCIA) procedure. This is a declaration that allows private operators to start, modify or stop production activities (craft, commercial, industrial), without any waiting time related to preliminary checks and inspections by the competent authorities. Additional procedures and documents are required for wind turbines with power greater than 200 kW and in the case of wind turbines installed in the proximity of Natura 2000 network sites. In response to this significant impulse to territorial transformation related to the installation of new wind turbines, no monitoring system has been implemented by the regional government.

4.2. Materials and Methods

The objective of this work is to assess the fragmentation resulting from the processes of territorial transformation in the low-density context of the Basilicata region. This study area, although characterized by a significant and consolidated phenomenon of depopulation, has undergone significant territorial transformation in recent decades due to different dynamics and different settlement system components. The Fig. 20 shows the methodological framework.

First of all, the urban sprinkling phenomenon concerning the dataset of residential buildings in the Basilicata region has been identified according to density indexes present in the scientific literature [19]. This allowed to discriminate the phenomenon of urban sprinkling from that of urban sprawl and consequently to assess the fragmentation of settlement system components through the sprinkling index. Subsequently, other fragmentation indices were used to evaluate the other settlement system components individually and by comparing them with each other. Before the assessment of the fragmentation dimensions, an important preliminary work concerned the collection and construction of the spatial database of the various settlement system components has been carried out. The following paragraphs describe the three main phases of the work: construction and processing of the dataset; aggregates formation and indexes to assess the fragmentation dimension: sprinkling index (SPX), infrastructural fragmentation index (IFI) and landscape fragmentation indexes.

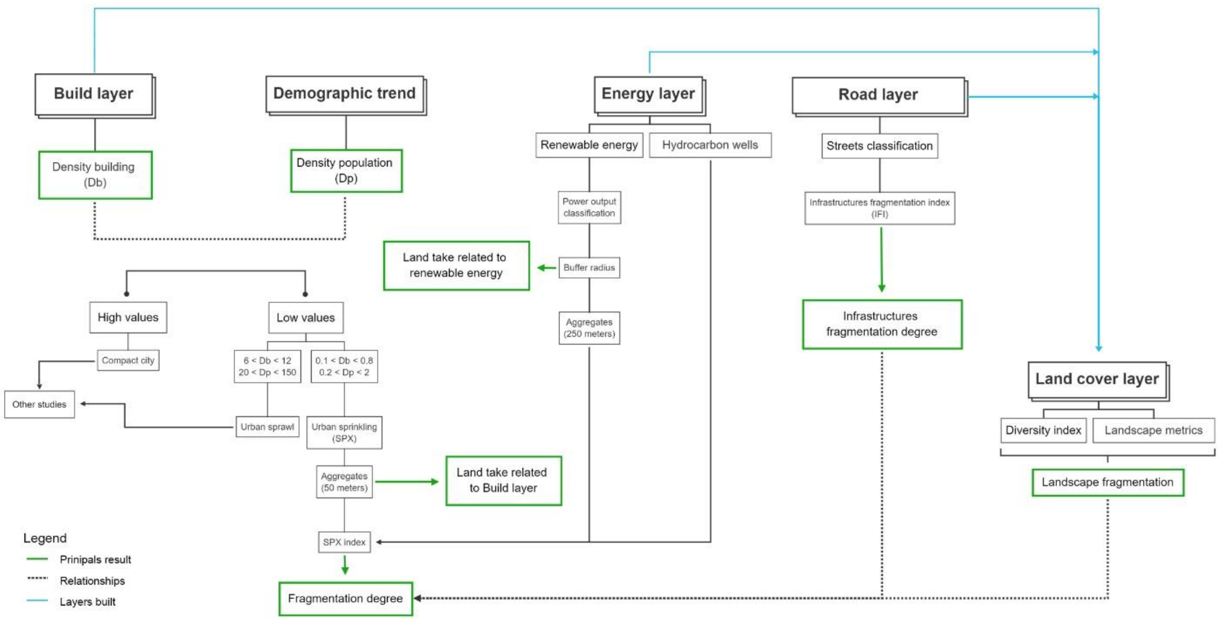


Fig. 20 Methodological framework

4.2.1. Data source and processing

The data set of this research, involved the construction of various layers from different sources: Regional Technical Cartography (RTC) produced by the Basilicata Region and distributed through the standards of the Open Geospatial Consortium (OGC) in the regional geoportal (RSDI - Geoportale Basilicata, [170]), National Energy Services Provider (GSE, [167]), data collected by the Italian Ministry of Economic Development related to hydrocarbon wells (MISE [171]), maps of land coverage and use of the European project Corine Land Cover (CLC [172]) and the digitalization of elements from aerial photogrammetric surveys at different dates: orthophoto and Google Earth. The temporal dimension of this data set was also evaluated through the identification of different temporal phases from the 50s to 2018 depending on the layer analyzed.

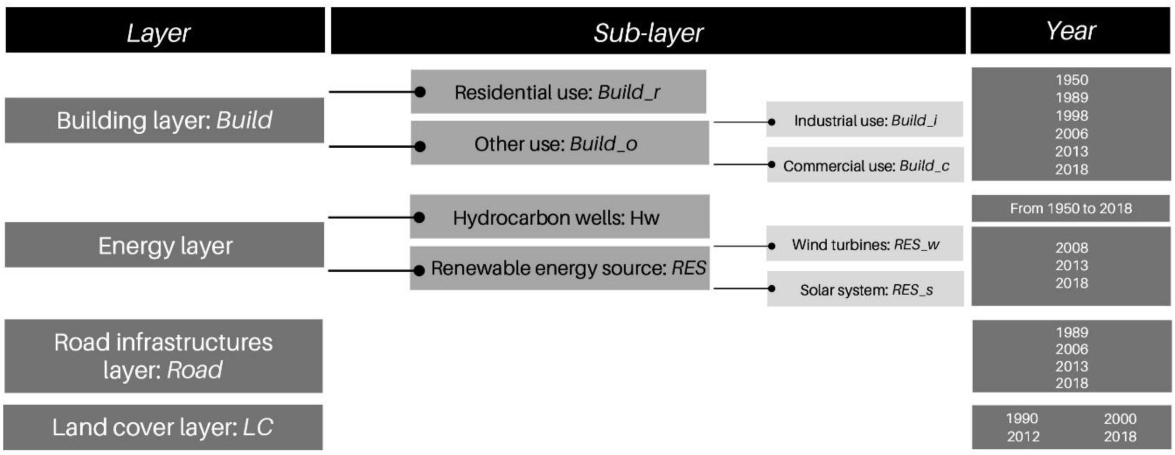


Fig. 21 summary of the datasets used in this research divided by layers and sub-layers.

Fig. 21 shows a summary of the datasets used in this research divided by layers and sub-layers with their corresponding acronyms and for each layer the temporal phase analyzed (*Year*) was reported.

Buildings, RES plants and hydrocarbon wells, road infrastructure and land cover maps are the main information layers used in this research. The building layer was compared with the demographic trend derived from the National Statistics Institute (ISTAT) [173]) considering a period from 1950 to 2018. In this paragraph, for each layer, the structure of the data will be described.

Building layer

The Building layer (Build) has been divided into two sub-layers: buildings for residential use (Build_r) and building for other uses (Build_o) which were in turn divided into two other sub-layers: buildings for industrial use (Build_i) and buildings for commercial, worship and public offices (Build_c).

For the evolution analysis of the settlement system regarding the building layer, the regional geo-topographic database of the RSDI, the orthophotos of the national geoportal of the Ministry of the Environment and the cartography of the Military Geographic Institute (IGM) have been used. The analysis of the settlement evolution has been developed since the 50s, considered the period of greatest economic and demographic growth in Italy. The selected sources allowed to identify six temporal phases: 1950-1989-1998-2006-2013-2018.

For the evolution of the settlement system, the technical cartography of the Basilicata region (scale 1:5000) in vector format, updated to 2013, was used as a starting reference. This spatial dataset contains information about the volume of buildings and their use (residential, commercial, industrial and other) and represents, to date, the official dataset that is homogeneously distributed over the entire territory of the Basilicata region.

Starting from this data, we proceeded backwards, comparing this information with the previous cartography and orthophotos by overlapping data and removing by topological modification of the vector data the buildings that did not exist on the previous dates. This comparison with the orthophotos, available as Web Map Service (*wms*) on the National Geoportal of the Ministry of the Environment [142], allowed us to construct the spatial analysis of time series on the basis of the following aerial photogrammetric surveys: 2006, 1998 and 1989. To analyze urban growth after the Second World War, we compared our spatial data with the 1:25,000 scale maps produced by IGM in the 50s. The evolution of the settlement system regarding Build at 2018 was obtained by reverse process. Specifically, we proceeded to modify the vector of 2013 by adding the buildings built after this date identified by overlapping with orthophotos of Basilicata updated to 2018.

The comparison between different data containing information on the distribution and the uses of buildings for different dates has provided a method to quantitatively identify the increase of the built environment over time and has allowed to obtain results on the whole regional territory. Recognizing that a dataset constructed in this way has several limitations - loss of data related to a possible increase in volume over time, accuracy depending on differences in map bases and their scale, long time of elaboration, differences in detection techniques - visual analysis by overlapping maps remain the most accurate methods to detect the effect of urban sprinkling characterized by the spread of small settlements in rural areas. The techniques of photointerpretation by remote sensing, certainly reduce processing times and allow to build an automated process, but especially for the time phases before the 2000s would lead to an excessive loss of data dependent on the Minimum Mappable Unit (MMU).

Population density (D_p) and residential building densities (D_b) indices (see A.2 Population density and building density in Appendix) at municipal and regional level have been estimated in order to analyze the relationship between the evolution of the settlement system and the demographic variable of the regional territory and to identify the phenomenon of urban sprinkling distinguishing it from that of urban sprawl. The demographic trend comes from ISTAT's ten-yearly population censuses: 1950-1991-2001-2011 and for 2018, from the population data collected annually. These were compared with the evolution of the settlement system regarding Build_r in the years 1950-1989-1998-2013-2018 in order to identify the relationship between the trend of the resident population and urban growth. According to Romano et al [19], urban sprinkling is characterized by D_b indices between 0.1 and 0.8 buildings per hectare and D_p indices between 0.2 and 2 inhabitants per hectare.

Energy layer

The energy layer has been divided into two sub-layers: the first concerns energy produced from non-renewable sources (such as fossil fuels) and then equipment for the production and extraction of hydrocarbons (hydrocarbon well Hw), the second concerns energy produced from renewable sources (RES) divided in turn into two sub-layers: wind turbines (RES_w) and solar farms (RES_s).

The Hw layer includes the location of all hydrocarbon production wells from 1950 to 2018. Hydrocarbon wells in point format were located by geographical coordinates and then polygonalized by ortho-photographic comparison for six temporal phases with the same methodology used for Build layer.

The RES layer was built through the integration of the different official information sources: RTC and GSE [167] with the digitization of the installations by aerial photogrammetric surveys on three dates (2008 - 2013 - 2018): regional orthophotos and Google Earth. The selection of temporal phases depends on different factors. The first wind turbines in the study area were installed in 2006 and can only be identified in 2008, the year of the first useful ortho-photos available. The year 2018 corresponds to the date of the last available ortho-photos for the entire region. As far as the RES_s layer is concerned, the plants for the production of energy from solar sources with a power greater than 200 KW started operating in 2012 and can be identified in 2013, the year of the first useful ortho-photos. All the solar farms were installed between 2012 and 2013 in accordance with the ministerial incentives for energy from photovoltaic sources (Ministerial Decree - DM 5 July 2012 [174]).

The RES layer includes information on the location, installed generation capacity and year of installation for wind turbines in point format and polygonal form for solar farms. Wind turbines have been classified according to their installed generation capacity into: small-scale, medium-scale and large-scale turbines according to the Table 4 which shows the evolution of all components of the RES layer in terms of installations number.

Since the RES_w layer obtained in this way is of the punctual type, in order to assess the land take related to the installation of wind turbines, it was considered an influence surface around the plants that includes in its evaluation also the areas consumed for the construction of the infrastructure services for access to the plants itself. The installation of wind turbines results in an occupation of land that is greater than the area corresponding to the sum of the individual pitches. For this reason, in order to integrate in the computation, the land taken by access roads and ancillary infrastructure, a method based on the assumption that the cumulative land consumption is proportional to the energy production of the farms has been used. The hypothesis was verified by a sample of sixty wind turbines (twenty for each power class) (for details see A.3 Wind turbines buffer radius in Appendix). The results lead to the identification of three influence radii (buffer radius) for each power class identified. Specifically, buffer radii of 15, 25 and 35 meters were identified for small, medium and large scale turbines respectively. The buffer radius allows to assess the land consumed by each wind turbine.

Table 4 Classification of wind turbines and photovoltaic systems by power output. For each time phase is reported the number of installation present on the regional territory.

RES	Power output [kW]	Class	Number			Total per class
			2008	2013	2018	
RES_w	< 200	Small-scale turbines	165	474	1129	1768
	200 ≤ power < 1000	Medium-scale turbines	32	96	74	202
	≥ 1000	Large-scale turbines	21	65	61	147
RES_s	≥ 200	Photovoltaic on the ground	-	241	-	241

Road infrastructures layer

The road infrastructure layer (Road) was built for 4 temporal phases from 1989 to 2018 using the 2013 RTC map as a starting point and proceeding similarly to the Build layer. Considering the detail required by this research, the RTC 2013 represents the official and exhaustive data source for the survey of road infrastructure. It consists of a linear vector dataset containing information on: type of road (highways, suburban, extra-urban and local roads), width of the roadway, type of road surface (asphalt, unpaved) and location (level road, viaduct, underpass, tunnel). The Road layers for the other temporal phases have been obtained through the integration between the RTC 2013 and photo interpretation processes with orthophotos of the national geoportal and google earth.

In particular, the following steps were followed: *(i)* introduction of the new road sections built after 2013 (date of the RTC) through topological modification by comparison with the google earth orthophotos (2018); (ii) elimination of the road sections built after 2013 using the orthophotos of the national geoportal to obtain the time phases of 1989 and 2006. At the end the 1989, 2006, 2013 and 2018 temporal phases have been individuated.

Land cover layer

The land cover layer was built for 4 temporal phases depending on the main data source CLC of the European project Copernicus [172] which produces maps of use and cover of the land every ten or six years since 1990. The CLC maps have a minimum mapping unit of 25 hectares for polygonal elements and a minimum detectable width for linear elements of 100 meters. For the peculiarity of the case study analyzed in this research, characterized by urban sprinkling and therefore by a strong urban dispersion, CLC maps are not sufficient to assess the fragmentation of the landscape caused by small urban settlements and other settlement system components included in this research. In this regard, the CLC maps have been integrated with the layers described in the previous paragraphs and 4 land cover maps have been realized in the years 1990, 2000, 2008 and 2018. Specifically, The CLC classes have been aggregated into 11 classes by adding new information layers to them. A further class, number 12, concerning the RES layer, has been added (Fig. 22).

CLC code	+ Layer	= Class	Code
111-112-141-142	Build_r	Residential building	1
121-122-123-124-131-132-133	Build_o, Hw and Road	Industrial and commercial building	2
241-242-243-244		Extensive agriculture	3
211-212-213-221-222-223		Intensive agriculture	4
311-312-313		Forests	5
332-333-334-335		Bare soils	6
323-324		Arbustive soils	7
231-321-322		Grass land	8
411-412-421-422-423		Wetland	9
511-512		Wather	10
521-522-523-331		Beaches and dunes	11
	RES_w and RES_s	RES	12

Fig. 22 Land cover layer construction outline

Specifically, CLC 1990 has been integrated with Build, Road and Hw layers of 1989; CLC 2000 with Build, Road and Hw layers of 1998; CLC 2008 with Build and Road layers of 2006 and Energy layers of 2008; CLC 2012 with Build, Road and Energy layers of 2013; CLC 2018 with Build, Road and Energy layers of 2018. The final maps have been rasterized with a resolution of 5x5 meters, a resolution that allows to map all the layers integrated in the land cover including roads and small buildings (see Fig. 23).

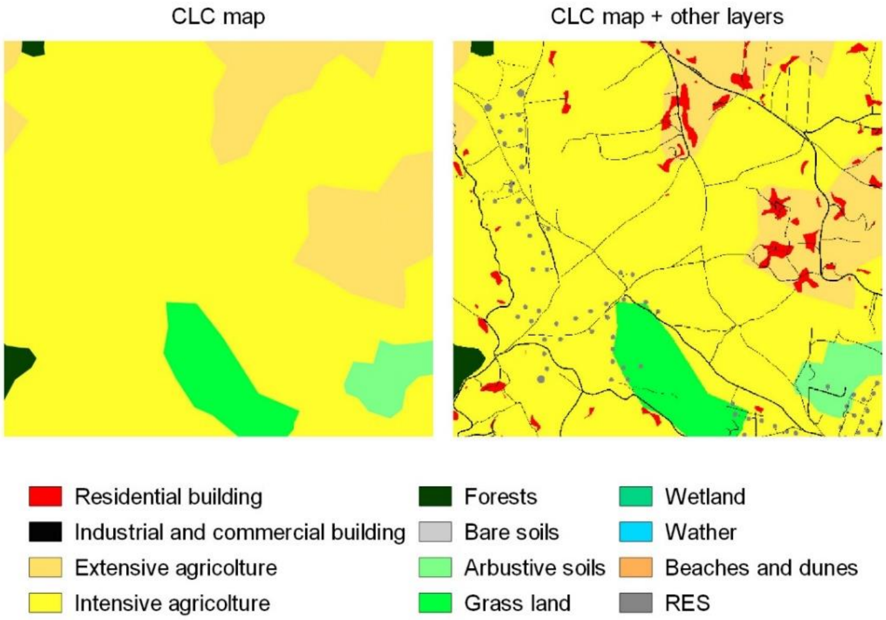


Fig. 23 On the left the CLC map with its original resolution, on the right the CLC map integrated with the layers built in the previous paragraphs.

4.2.2. Aggregates formation

In order to understand the evolutionary dynamics of urban expansion, the settlement system components have been aggregated by transforming the individual elements into more complex polygons according to a fixed threshold distance. This allows to move the analysis from punctual to spatial, investigating the spatial configuration of the elements, their density as well as the urban dispersion. The aggregates are useful in analyzing transformation dynamics: an increase in the number of elements does not always correspond to a greater number of aggregates; therefore, two or more elements can be considered an aggregate when the distances between them are lower than the established threshold. Fragmentation increases with the increase of aggregates number. On the other hand, a decrease in the number of aggregates corresponds to a compaction of the urban area due to the expansion of the settlement system components close to the existing ones, to build a single larger aggregate. In a rational and sustainable urban expansion model, only an increase in the aggregate area is expected, implying the development of compact urban area.
The aggregates formation concerned the Build and RES_w layers.

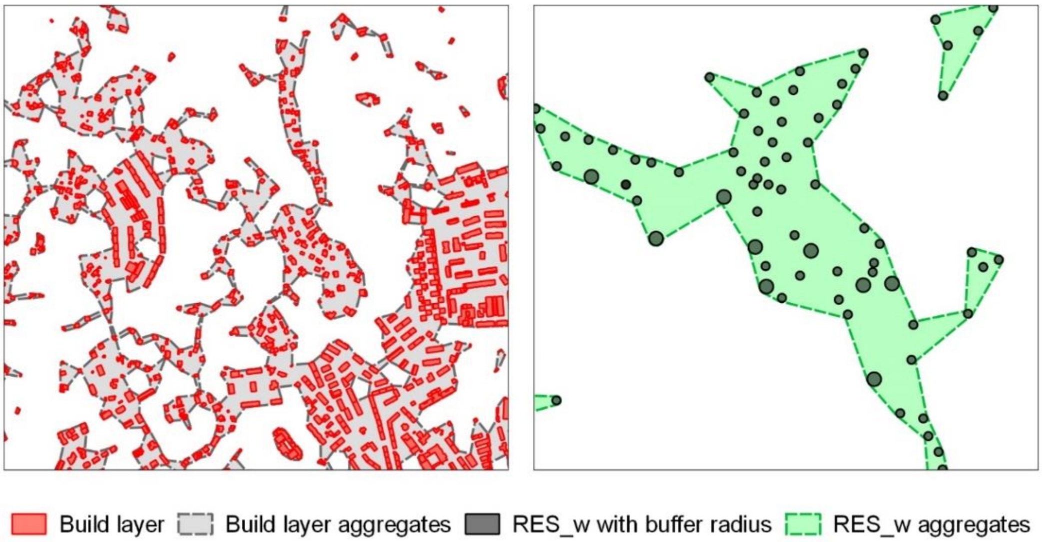


Fig. 24 Example of aggregates construction with Build layer and RES_w layer.

With regard to the Build layer, the aggregate formation allows to consider not only the building footprint but also the land consumption related to roads, parking lots and all public services related to the building. We consider the Build aggregation as a new method to represent groups of buildings within an urban area. The idea is different, from the traditional concept of an urban center that includes the continuity of the buildings, streets and enclosed lots. Defined the assumptions, two or more buildings are considered aggregates when the distances between the footprint's buildings are less than an established threshold. Among the various aggregates obtained with 25, 50, 100 and 200 meter of threshold distances, the 50-meter threshold allowed to perimeter the urban aggregates for each temporal phases. This distance was the most appropriate to represent the Build layer aggregation in Basilicata region.
For the RES_w layer the aggregates formation allows to quantify the surface loss after the installation of a group of wind turbines. We are referring principally to wind turbines classified at small and medium scales whose distance, according to the PIEAR [169], cannot be less than 3 times the rotor diameter

(max distance from 60 to 150 m for small and medium scale turbine respectively). It should be noted that this distance has been evaluated only on the basis of technical effects of the installations themselves and not in terms of land take and loss of ecosystem services. The effects of the installation of wind turbines (e.g., loss of habitat quality) extend over an area greater than the sum of those calculated with buffer radius. The RES_w aggregate is a polygon containing two or more wind turbines whose distance (between the polygons of the buffer radius) is below the threshold of 250 meters. The basic assumption is that the areas between the turbines partially lose their suitability for land use previous to the construction of the wind turbine. In fact, the area of the aggregate includes not only the pitch, road access and technical rooms of the plant itself, but also a measure of the total area irreversibly subtracted from its natural vocation.

4.2.3. The dimensions of fragmentation

Sprinkling index – SPX

Among the different indices available in the literature (landscape metrics, shape indices, mean Euclidean nearest neighbour distance, area-weighted shape index and aggregation index [175–178]), the sprinkling index (SPX) [19,20] was used to assess the landscape fragmentation caused by the expansion of the settlement system. This, based on the mean Euclidean nearest neighbour distance, analyzes the fragmentation of an urban settlement through a purely geometric evaluation. Assuming that the circular shape is the most compact possible one for the urban expansion, the index is essentially based on the computation of Euclidean distances between the different urbanized areas present in a given area taken as reference. SPX index is then relative to the territorial surface taken as reference that can be a regular grid, the municipal, provincial administrative limits, the limits of protected areas such as NATURA 2000 network sites and so on. It was applied for the first time by Romano et al.[19] dividing the region Umbria with a regular grid of 1 sqkm and it is expressed with the follow equation (Eq a).

Eq a

$$SPX = \frac{\Sigma\sqrt{(x_{i-}x^{*})^2 + (y_{i-}y^{*})^2}}{R}$$

where x_i and y_i represent the position of the centroid of each aggregate while x^* and y^* are the coordinates of the centroid of the largest aggregate present in each territorial unit taken as reference. R is the radius of equivalent circular area corresponding to the sum of the all aggregates surfaces present in the territorial unit.

SPX has a range of allowable values from 0 to +∞. The higher the index, the higher the degree of territorial fragmentation. Zero value represent “not fragmented” cells, i.e. a single aggregate with an area considerably lower than the grid or an aggregate with an area of exactly 1 km^2 (the optimal situation, difficult to find in reality - a kind of urbanization developed according to the circumference shape). For this reason, it is always advisable to correlate SPX index spatial distribution with the total footprint of occupied artificial surface for each cell. Null SPX values correspond to “not urbanized”, i.e. cells with no urban aggregate. The degree of fragmentation of a territory grows with the increase of the SPX index.

The SPX index was calculated for different temporal phases with two territorial units - a regular grid of 1 square km and the administrative limits of the 131 municipalities of Basilicata region - and considering layers in their original form or aggregated according to the methodology described in the previous paragraph. Specifically:

- SPX_Build_1: SPX index for Build layer in aggregate form with a regular grid of 1 square km for six temporal phases between 1950 and 2018;
- SPX_Build_m: SPX index for Build layer in aggregate form based on the municipality's administrative limits for six temporal phases between 1950 and 2018;
- SPX_RES_w: SPX index for RES_w layer in aggregate form with a regular grid of 1 square km for three temporal phases from 2008 to 2018;
- SPX_tot: SPX index for Build layer aggregates, Hw layer, RES_s layer and RES_w aggregates form with a regular grid of 1 square km for six temporal phases between 1950 and 2018.

Since the SPX index is the expression of the distribution of urban aggregates on the territory divided into homogeneous territorial units, its variation over time allows to identify the main urban expansion dynamics and specifically: fragmentation and compaction. By analyzing the temporal variation of the sprinkling index (*ΔSPX*) from an initial time t_0 to a final time t_1 is obtained: $\Delta SPX_{(t_1-t_0)}$ > 0: Urban fragmentation; $\Delta SPX_{(t_1-t_0)}$ < 0: Urban compaction; $\Delta SPX_{(t_1-t_0)}$ = 0: No transformation.

The SPX index is considered a useful tool for monitoring fragmentation linked to the different components of the settlement system. It allows to consider simultaneously the extension, the shape and the distance between the different geometries present in the same cell over different temporal phases.

Infrastructures fragmentation index - IFI

The fragmentation from mobility and transport infrastructure leads to the division of the landscape into smaller patches with effects on soil consumption and ecosystem services such as habitat loss, plant mortality and isolation of animal and vegetal species [179,180]. As a matter of fact, together with the other components of the settlement system, transport infrastructure is transforming European landscapes into increasingly smaller patches, with potentially devastating consequences for flora and fauna across the continent [181]. The fragmentation of the landscape caused by road infrastructure will be assessed through the Infrastructure Fragmentation Index (IFI) [147,175,176,182]. IFI index defines the extension of the multimodal mobility system, including all types of roads and the railway network, in relation to a territorial area taken as a reference. In this research the IFI index will be calculated with reference to a regular grid of 1 square kilometer mesh (IFI_1) and based on the administrative limits of the 131 municipalities of the Basilicata region (IFI_m). It is expressed by the Eq b and is formulated starting from the infrastructure density index to which an occlusion coefficient dependent on the type of road is added.

Eq b

$$IFI = \frac{\sum_i^n (l_i \times o_i)}{A_u}$$

Where l_i is the length of the single section of infrastructure (excluding discontinuities such as viaducts, bridges and tunnels) in meter, o_i represent eco-systemic occlusion coefficients dependent on the type of road infrastructure and A_u is the surface of the territorial unit of reference in sqkm.

The IFI index can be implemented in different ways and depending on the method of calculation of the ecosystem occlusion index it is possible to obtain the weighing of the lengths of the infrastructure segments calibrated on their occlusivity character. The occlusion coefficient values have been defined on the basis of a comparative evaluation for the different types of infrastructure starting from those established by Romano and Zullo 2015 [175]. Assuming that the o_i coefficient has a range of values between 0 and 1, higher values have been assigned to the road types with the highest degree of occlusion (such as highways) and lower values to the other types. Excluding road in tunnels and on bridges/viaducts/overpasses as they are not occlusive for natural habitats, the following values to the occlusion coefficients have been assigned: $o_1 = 1$ for highways, railways and main suburban roads that show a generally total occlusions resulting from the presence of perimeter barriers; $o_2 = 0.7$ suburban secondary roads with an occlusion generally not physical but caused by noise and vibration caused by permanent movement); $o_3 = 0.5$ secondary road network, local roads, neighborhood urban roads, slip roads with a medium level of occlusion characterized by absence of physical barriers but due to disturbance conditions and physical presence of infrastructure; $o_4 = 0.3$ secondary road network, also includes dirt roads. They are characterized by variable daily traffic volumes from very high - for example during the day - to very low - for example during the night - but with a favorable relationship with the local morphology in terms of occlusion.

All road sections in tunnels and on bridges/viaducts/overpasses have been excluded from the computation of the IFI index because they do not constitute physical barriers and are therefore not occlusive for natural habitats. It should be emphasized that these road sections, while not generating fragmentation, constitute, given their artificial character, land take to all effects.

The IFI index has greater values depending on the length of the road sections and consequently the occlusion in the examined territory. It has been calculated for the Road layer, for four temporal phases: 1989, 2006, 2013 and 2018. As the IFI index increases, the degree of fragmentation from road infrastructure increases.

Landscape fragmentation

Analyzing the fragmentation of the landscape provides the possibility to describe the structural characteristics of the landscape, to document the changes and the relationship of these indices with the occurrence of different species or groups of species [183–186]. The landscape metrics analyzed are specified following. (i) Land cover: metric expressed in number of pixels in each patch for every land use class. (ii) Landscape Proportion: defines the proportion of each land use class to the total of the analysed area; the sum of the indices for all identified land use classes will return the unit value. (iii) Edge Length expresses the number of pixels present on the patch borders for each class of land use analyzed, a sort of patch perimeter. It is useful to represent the landscape configuration in relation to habitat loss and environmental fragmentation. (iv) Largest patch index: quantifies the percentage of the total landscape area included in the largest patch. It is calculated by dividing the area of the largest patch of each land cover class by the total area. A high index corresponds to the presence of a large patch and can be an expression of a little fragmented landscape. When this index decreases in a temporal analysis, it means that the size of the largest patch decreases resulting in landscape

fragmentation. (v) Edge density, (vi) Number of patches and (vii) Splitting index are metrics that describing the landscape structure at quantitative level [130,187,188].
A diversity index can be defined as the probability that two randomly taken organisms in a given community are not of the same species [189]. The Shannon-Wiener Diversity Index (H_{SH}) is a statistical index based on information theory. It represents the amount of "information" per individual or type of patch, in this specific case [190]. The SH index is expressed by Eq c:

Eq c

$$SH = -\sum_{i=1}^{S} p_i \log_2 p_i$$

Where: *pi* is the proportion of the landscape occupied by the patch type (class) *i*. Shannon's diversity index returns the sum of the proportions of each class over the total. The SH index is a type of diversity index often applied to the assessment of specific diversity and used extensively in the field of landscape ecology [191]. It has a range of values from 0 to ∞. A high value of SH indicates an equal proportion of the categories, while a low value expresses the strong dominance of one category, combined with a poor representativeness of the others.
Simpson's index [136] (H_{SI}) is expressed by Eq d:

Eq d

$$SI = 1 - \sum_{i=1}^{S} p_i^2$$

Where: $\sum_{i=1}^{S} p_i^2$ represents the probability (*p*) of randomly choosing two organisms of the same species (*i*) (any of the available S species). The maximum value is reached at $\mathrm{p_i} = \frac{1}{\mathrm{S}}$ for every i. Simpson's index varies between 0 and 1. The higher the index, the more likely it is that every two randomly designed cells will be different types of patches.
The Evenness index (E_V) - also called uniformity or equitability - describes how equal are the specific abundances between them, that is, how uniformly the individuals of a population are distributed among the species [192]. E_v is obtained from the ratio between the calculated value of H_{SH} and its maximum value with respect to the number of species present in the data sample.
Landscape metrics and diversity indices were calculated in the study area for four temporal phases (1990, 2000, 2012 and 2018) considering LC layer. The analysis of landscape fragmentation allows to understand how the overall landscape has changed as a result of urban transformations due to all settlement system components.

4.3. Results

In this section will be presented and discussed the results obtained divided by indexes applied to the various settlement system components. First, the results of building and population density that allow to identify the dynamics of urban sprinkling are presented, followed by urban sprinkling results for Build layer, RES_w and SPX for all components of the settlement system. At the end, the results of the IFI index and landscape fragmentation metrics are described. The results will be discussed and compared with each other.

4.3.1. Building Density and Population Density

The Build layer have been classified for each of the six temporal phases into residential and other uses. The number of buildings for Build_r and Build_o is shown in the histogram (Fig. 25) for each temporal phase. Excluding the major expansion trend between 1950 and 1989 that followed the post-war II economic boom, the number of buildings has continued to increase since 1989. They show a positive trend ranging from 13% (1989-1998) to 1% (2013-2018) for Build_r and from 22% to 4% for Build_o for 1989-1998 and 2013-2018 respectively. This slightly downward trend of Build_r in recent decades, highlights how land take in recent decades is more driven by other settlement system components rather than residential buildings.

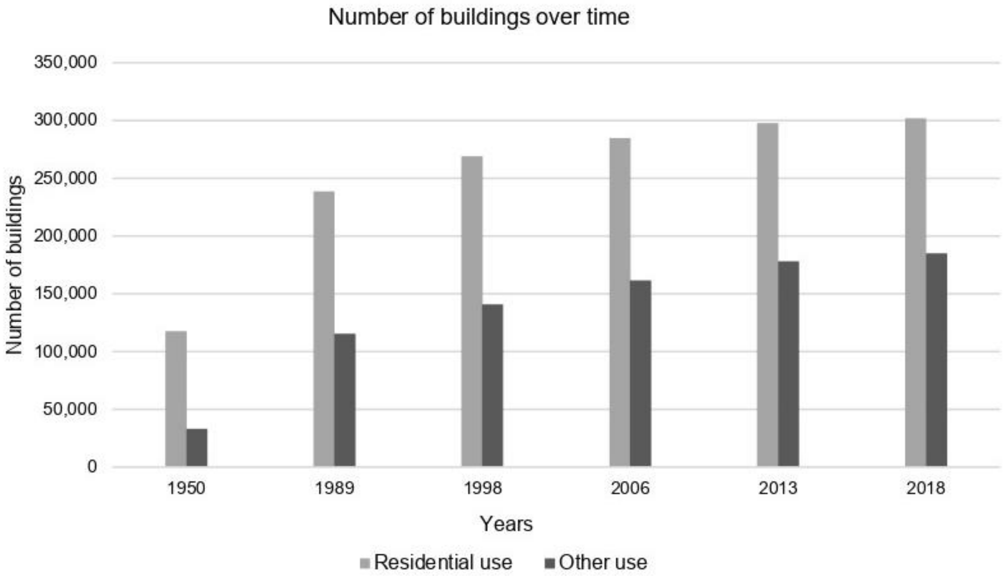


Fig. 25 Comparison between residential buildings and other uses in the six temporal phases considered.

Since the Basilicata region is characterized by low settlement density, it was considered appropriate to relate the D_b and D_p index in order to identify the main transformation dynamics of this territory. D_b and D_p were calculated for the temporal phases from 1950 to 2013 with the Eq j and Eq k, the results are shown in the Tab ii in the Appendix. The year 2018 has not been considered since there is no official data concerning the use of buildings for each municipality (only data at regional level are available). Fig. 26 shows the maps of the D_b and D_p percentage variation for three temporal intervals (1950-1990; 1990-2000 and 2000-2011) for all municipalities.

Only some municipalities show D_b and D_p values slightly higher than those typical of urban sprinkling but overall, the average values calculated for the entire region fully respect the ranges of values characteristic of the dynamic of urban sprinkling. Table 5 shows the results grouped for the entire region and for each of the temporal pahase considered. Specifically: D_p assumes values between 0.63 to 0.56 inhabitants per hectare and D_b between 0.12 and 0.30 residential buildings per hectare.

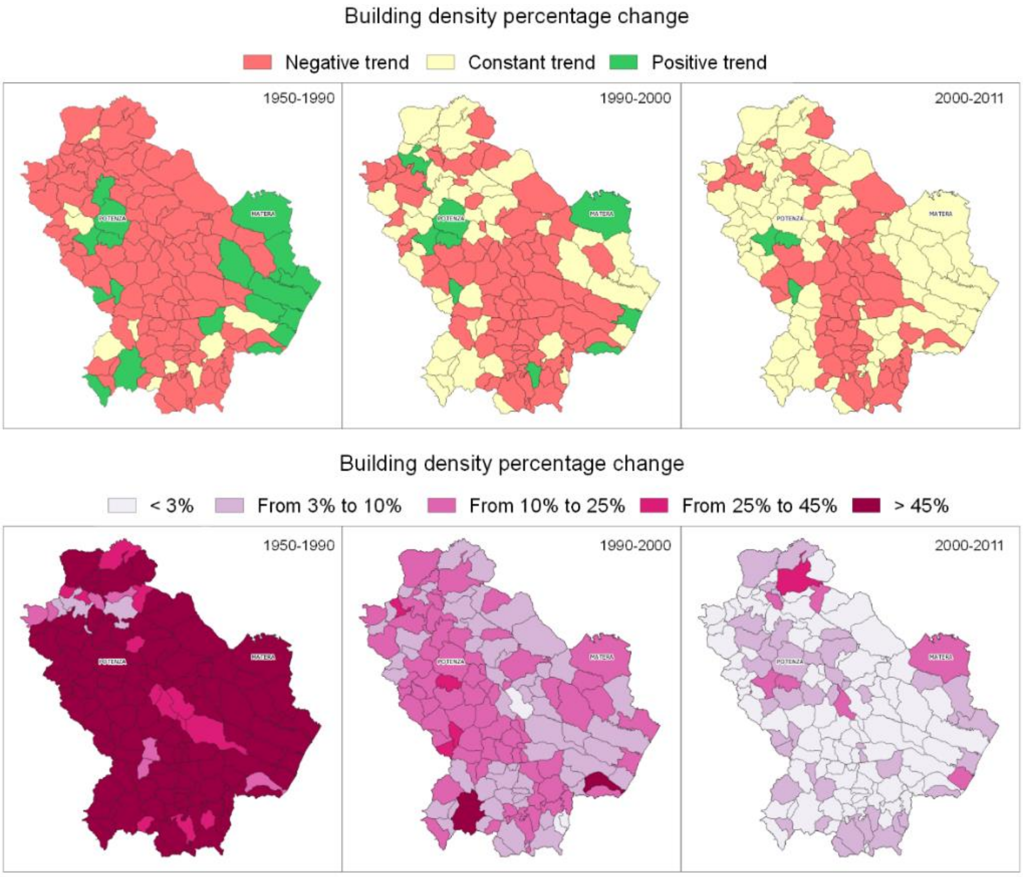


Fig. 26 Comparison between D_p and D_b variation for each municipality of Basilicata region.

Between 1950 and 2013, in 108 of the 131 municipalities, there was a negative demographic trend, which does not correspond to a reduction in urban expansion, by contrast, it has a positive trend. In most municipalities, the expansion of residential buildings was completely disproportionate to demographic change, showing that the development of settlements was not due to a real need for housing. These results show a disjointed trend, defined in the literature as "decoupling" [158,159], as already expressed in the description of the study area (par. 4.1). The graph (Fig. 27) in fact shows how the increase in the number of residential buildings in the region has not adapted to demographic trends. In particular, while the resident population decreased from 1950 to 2018, the residential building stock has increased over time.

Table 5 Variation of population and buildings in the Basilicata region over time

Year	Population [n Inhabitants]	Build_r [n]	D_p [inhabitants/ha]	D_b [Build_r/ha]
1950	627,586	117,687	0.63	0.12
1989	610,186	238,603	0.61	0.24
1998	597,468	269,019	0.60	0.27
2006	591,338	285,072	0.59	0.28
2013	578,391	297,810	0.58	0.30
2018	562,869	302,010	0.56	0.30

Although the considerable discrepancy between the data of 1950 and those of 1989 is justified by the fact that 1950 represented a period of economic boom and post-war reconstruction, in which the settlement development was derived from real housing needs; the land take between 1989 and 2013 is not justified and seems to be a response to an unsustainable living culture that considers the soil as a product. This evidence allows to consider also another preliminary hypothesis: the divergence between supply and demand of residential function at regional level may depend on the lack of an urban regulation system, and also be linked to a specific demand for new residential buildings characterized by higher standards in technological and architectural features.

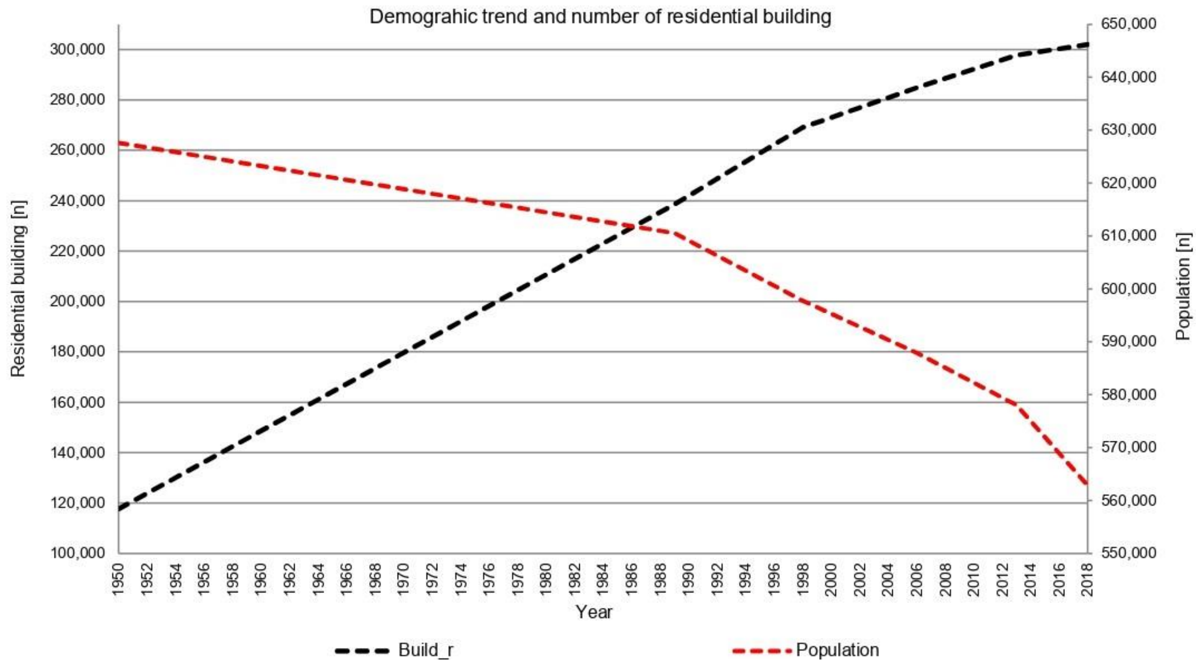


Fig. 27 Comparison between number of residential buildings and demographic trend between 1950 and 2018.

Following the average territorial parameters defined by Romano et al [19]. for the characterization of urban sprawl and urban sprinkling phenomena, a large part of the territory of Basilicata region can be considered affected by the phenomenon of urban sprawl if we consider the extended Italian model. The remaining minimal part has been affected by the phenomenon of urban sprinkling according to the Italian linear model.

4.3.1. Sprinkling index for Build layer

SPX_Build$_1$

The SPX index has been calculated over the entire study area divided into cells of 1 km2 through a grid randomly positioned according to the regional perimeter. For each of the six temporal phases, the Build layer have been aggregated with the methodology described in Paragraph 4.2.2 considering a threshold distance of 50 meters. The SPX index calculated with the Eq a produced a value for each grid cell which was then expressed as the fragmentation degree. According to Fraile et al., 2016 [193] in order to ensure a high internal homogeneity between the various classes of fragmentation, the method of classification of natural breaks has been used to define the fragmentation thresholds. The natural breaks method uses an optimization algorithm (Jenks optimization [194]) that minimizes the sum of the variance within each of the classes and finds groupings and models inherent to the examined dataset. Table 6 - excluding the Null value that correspond to "no urban" cells - shows the subdivision of SPX in six fragmentation degrees with a variability between 0 (not fragmented) and about 200 (high fragmentation)

Table 6 Fragmentation degree according to SPX_Build_1

Fragmentation degree	SPX
No urban	Null
Not fragmented	SPX = 0
Low fragmentation	0 < SPX ≤ 19
Medium-low fragmentation	19 < SPX ≤ 50
Medium fragmentation	50 < SPX ≤ 87
Medium -high fragmentation	87 < SPX ≤ 142
High fragmentation	SPX > 142

Fig. 28 shows a sampling of the 6 degrees of fragmentation with the respective sprinkling indexes. It is evident that the same classes of fragmentation have a different occupied cell surface by aggregates. In the case of " Not fragmented", cell a) has a large area of the aggregate as opposed to cell b) where the area is very small; both correspond to the “Not fragmented” degree since they constitute a single aggregate. Similarly, in the case of "High fragmentation", cells a) and b) have a different surface occupied by the aggregates but in both cases, these are small and dispersed in the cells.

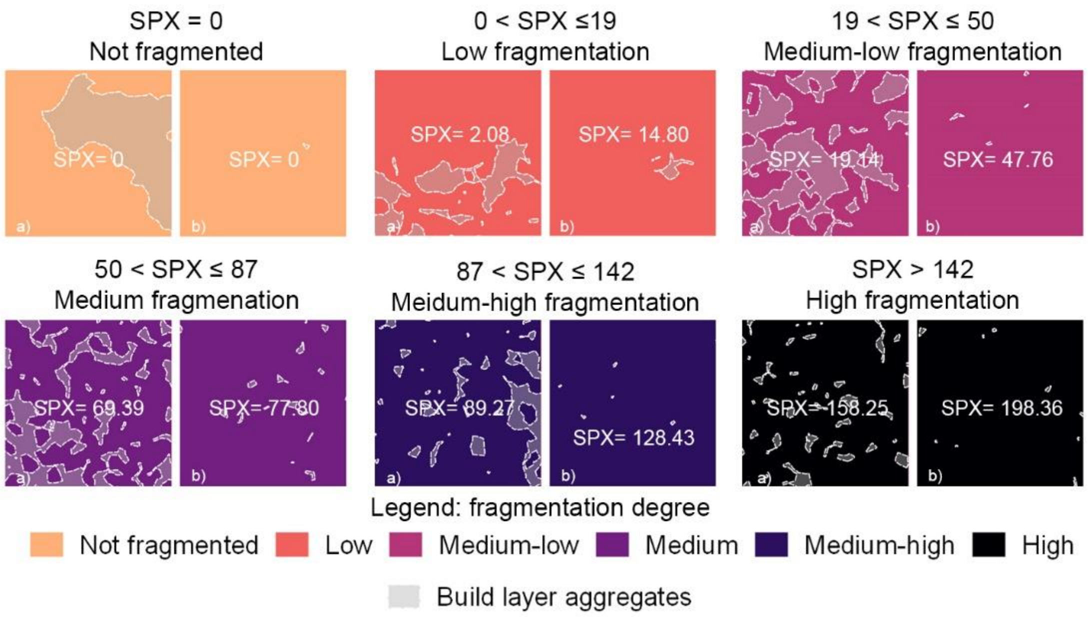


Fig. 28 SPX sampling for different fragmentation degree a) and b) are indicative of how the cell has the same fragmentation degree despite having a completely different occupied surface.

Fig. 29 shows the results of the sprinkling index for the six temporal phases and the percentage amounts of cells in the various fragmentation degrees. From the maps it is possible to observe how in some cases, the cells characterized by low fragmentation at time t_0 have moved to high fragmentation values at time t_1 and vice versa. This means, in the first case, that new buildings have been built in the cell following the dynamics of urban sprinkling; while in the second case (from high to low fragmentation), new transformations have occurred in the cell adjacent to the previous ones, compacting with the existing aggregates and reducing the fragmentation degree in that cell. In the presence of new settlement demand, it would be advantageous and more sustainable to follow this last transformation mode, which aims to cover soil near existing urban agglomerations and not to consume soil in those cells with high fragmentation degree or worse classified as No urban.

Over the years, fragmented areas have increased at the expense of No urban areas. By 2018, No urban areas, free from aggregates constituted by Build layer, have decreased by 52% compared to 1950. The greatest transformations took place between 1950 and 1989, when the cells classified with a high degree of fragmentation increased by 50% and those Not fragmented (consisting of a single aggregate) decreased by 26% compared to 1950. This trend shows how the urban sprinkling took place in those years when the great new expansions were justified by the economic boom of the II World War period, which led to an increase in demand for new settlements. However, although more limited, urban sprinkling continued to occur in the other temporal phases analyzed. As a matter of fact, between 1989 and 2018, although more slowly, cells classified with a low to medium-high degree of fragmentation continued to increase at the expense of No urban, Not fragmented and highly fragmented cells. This results in further land take that occurred in a disorderly manner and without following any principle of sustainability. The SPX index calculated on the basis of the grid allows to measure the urban sprinkling phenomenon in quantitative terms; however, the quantification cannot be considered univocal, since the grid translation would be sufficient to obtain different results. However, it provides an exhaustive analysis of the transformation dynamics and allows to identify the cells on which to work in order to limit the fragmentation and consequently the land take.

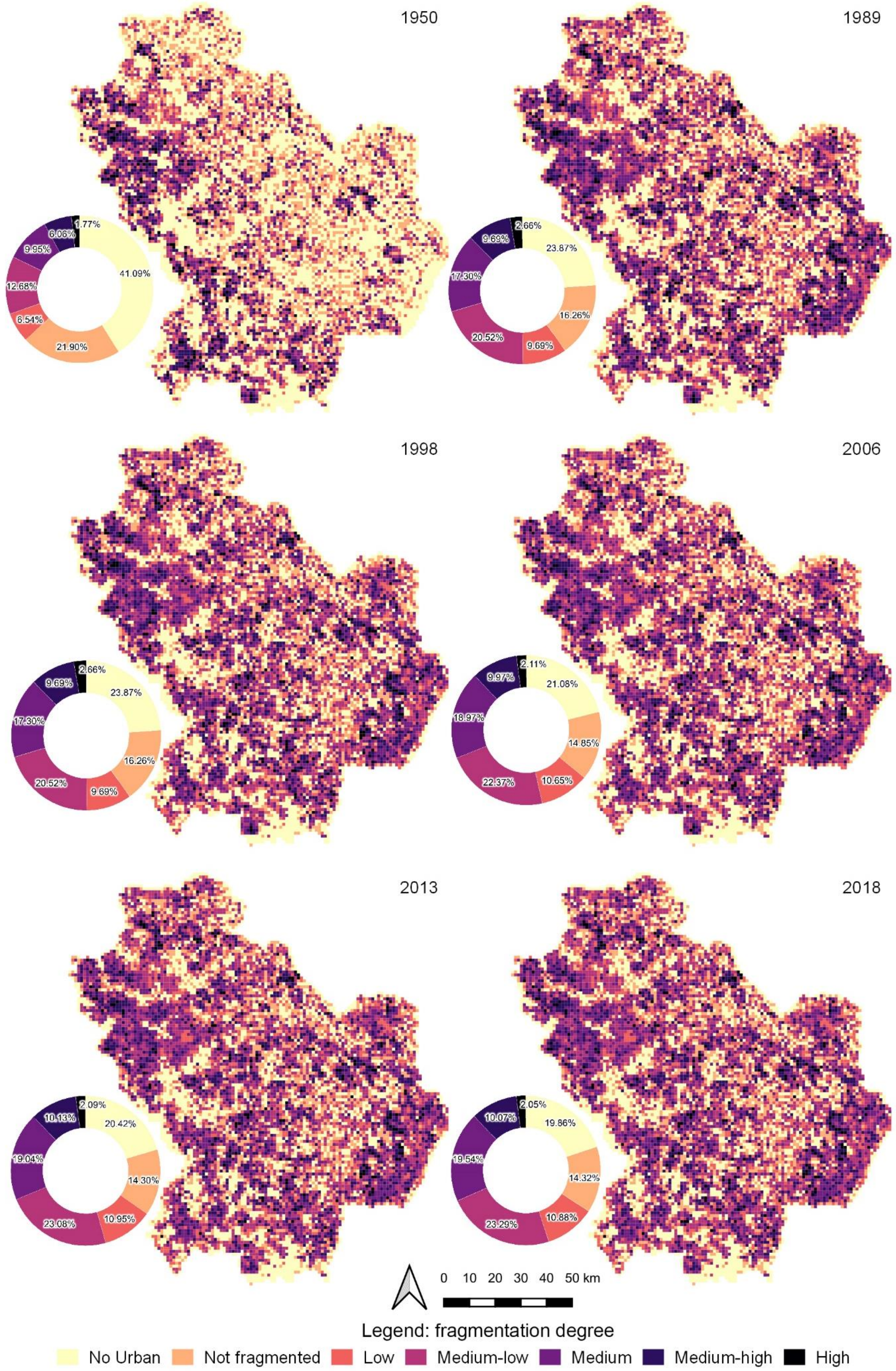


Fig. 29 Urban fragmentation at regional level with a grid of 1 square km for six temporal phases (SPX_Build$_1$).

SPX_Build$_m$

In this section the results of the SPX index calculated considering as reference territorial units the administrative boundary of 131 municipalities in the Basilicata region, are reported. The index was calculated with the aggregates of Build layer, varies between values of 200 (low fragmentation) and about 8000 (high fragmentation) and returns fragmentation degree for each municipality and for each of the six temporal phases analyzed. Table 7 reports the five fragmentation degrees associated with the SPX index values obtained using the natural brecks classification method explained previously.

Table 7 Fragmentation degree according to SPX_Build$_m$

Fragmentation Degree	SPX 1
Low fragmentation	SPX ≤ 1190
Medium-low fragmentation	1190 < SPX ≤ 1933
Medium fragmentation	1933 < SPX ≤ 3130
Medium-high fragmentation	3130< SPX ≤ 5377
High fragmentation	SPX > 5377

Fig. 30 shows the six maps representing the fragmentation degree for each municipality and the percentage of municipalities for each degree of fragmentation in the 6 temporal phases. The majority of the municipalities are in the fragmentation degree from low to medium-low. High fragmentation municipalities double in number from 1950 to 2018 from 4, become 8. The main differences between the temporal phases concern to the transition of some municipalities from a low to a high fragmentation degree and then back into the low degree. In order to give an example, we cite the Montescaglioso municipality, positioned below that of Matera (see Fig. 30). This, in 1950 has a medium fragmentation degree which increases from 1989 to 2006 (High), decreases its degree of fragmentation (medium-high) in 2013 and returns to a high degree of fragmentation in 2018. This fluctuating fragmentation degree shows how -in some municipalities- urban policies have not paid attention to the form of urban expansion, favouring an uncontrolled and fragmented development. Different is the case of Tito municipality, located south-west of that of Potenza. From medium fragmentation degree in 1950 it moved to the fragmentation class below (medium-low). The new expansions have taken place in the proximity of those already existing favouring the compaction (densification). Globally between 1989 and 2018, the number of municipalities with low fragmentation decreased from 40 to 37, while the number of municipalities with medium fragmentation increased from 36 to 40. Between 1998 and 2013, the situation remained almost unchanged. In contrast, no change occurs in the number of high-fragmentation municipalities, which remains unchanged after 1950.

This method of computing SPX index allows an assessment of each municipality's tendency to consume soil. The graph (Fig. 31) shows a comparison between the percentage change in SPX and demographic trend that provides further considerations. Recognizing the different evolutionary dynamics between the first and second temporal interval (1950-1989), a period in which the economic and settlement dynamics were influenced by the major economic boom of post-WWII, the variation from 1989 to 2013 was considered.

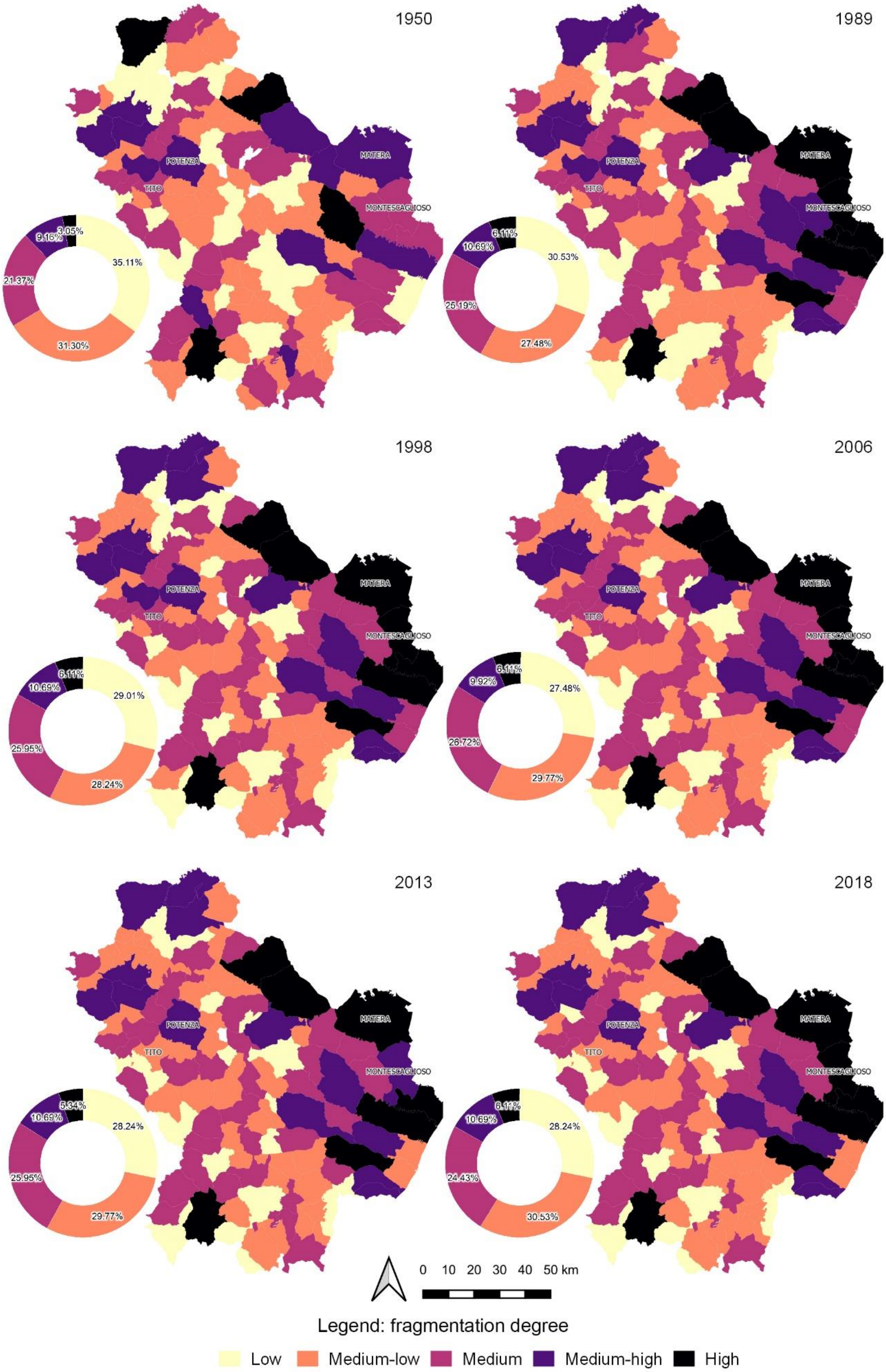


Fig. 30 Urban fragmentation at regional level with respect to the municipalities boundary for six temporal phases (SPX_Build_m)

In this period, 53% of municipalities (69 out of 131) had a positive percentage change in the SPX index, and thus a more or less marked trend toward fragmentation. In contrast, the remaining 47% showed a propensity for compaction. In the graph in Fig. 31, the x-axis shows the change in the SPX index while the y-axis shows the demographic variation. Municipalities are represented by gray and blue dots for the 1989-1998 and 1998-2013 temporal phases, respectively. Positive values of the ΔSPX correspond to an increase in the fragmentation degree, while negative values correspond to a decrease in fragmentation. Four quadrants are identified (anti-clockwise) in which the municipalities are distributed according to their evolutionary dynamics.

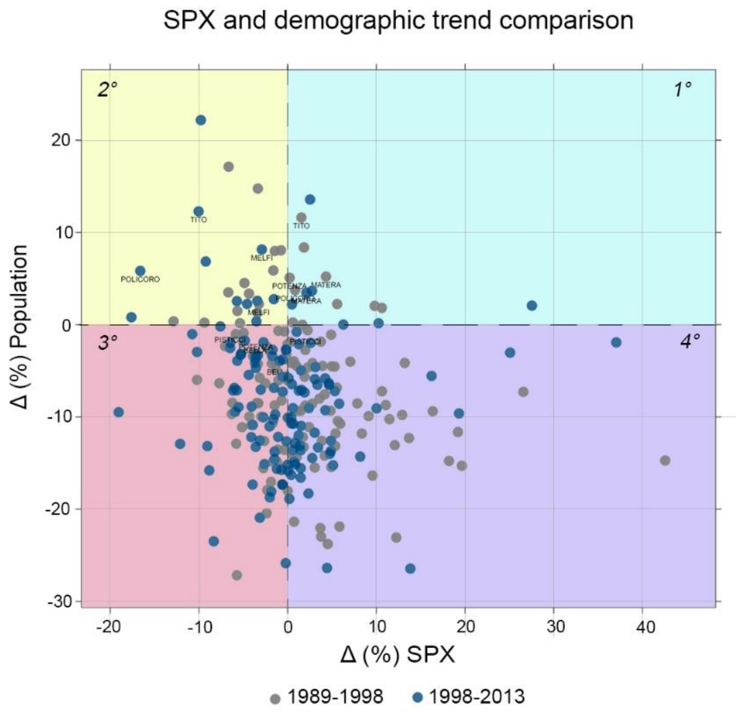


Fig. 31 Comparison between the SPX percentage variation and the percentage population change between 1989 and 1998 and 1998 and 2013

The fourth quadrant, which contains the majority of municipalities (62 and 53 respectively for the two temporal phases), represents the poorest sustainable behaviour. In contrast to a demographic decrease, an increase in SPX and fragmentation occurs. In the absence of settlement demand, land take has continued to increase and mostly in a fragmented manner. The second quadrant, which represents the most sustainable scenario, contains a small number of municipalities (about 10%) in both temporal phases. A positive demographic trend corresponds to a decrease in the degree of fragmentation. In other words, these municipalities have implemented policies over the years in favour of compacting the existing urban nucleus. Quadrants 1 and 3 represent intermediate conditions. From the graph, particular situations emerge in which some municipalities change their position by shifting from one quadrant to another during the two temporal intervals. For example, the Tito's municipality improved its behavior in terms of fragmentation, moving from the first quadrant to the second. The Policoro's municipality, characterized by a strong urban expansion along the Ionian coast due to its touristic vocation [195], has worsened its situation, moving from the second quadrant to the first.

4.3.2. Sprinkling index for the wind turbines installation (RES_w)

In this section, the SPX index results for the RES_w layer aggregated with 250 meter threshold distance are presented. They will finally be compared to SPX_Build_1 for the last three years (2008, 2013 and 2018). The graph in Fig. 32 shows the temporal evolution of wind turbines: the histogram represents the number of wind turbines for each class, while the line diagram shows the occupied surface (in hectares), calculated with the buffer radius. The classification of wind turbines by power output provides a clear picture of the current status of the study area. It is evident how to a very high number of Small-scale turbines corresponds to a very large overall occupied surface (125 ha), the 56% of the total surface. As far as the spatial distribution is concerned, moreover, the small turbines, due to their high number, are dispersed over the territory in a fragmentary way. In the Basilicata region, as of the year 2018 there are 2117 wind turbines with a total occupied surface area of 221 ha.

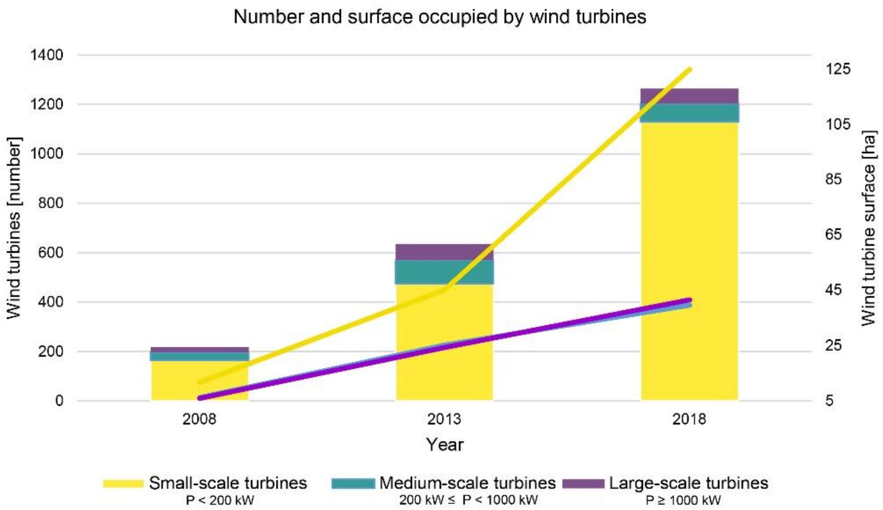


Fig. 32 Graph of the number of wind turbines (histogram) and area occupied in hectares (lines) for each year and for each power output class.

The SPX index was applied on the basis of the same 1 sq. km grid used for the Build layer. The results, for each cell were classified into various degrees of fragmentation as shown in the Table 6. In this case, the “No urban” class corresponds to those cells that are not occupied by RES_w layer.

The Fig. 33 on the bottom right shows the distribution of fragmentation degree in an area taken as an example for the three years. It can be seen that from 2008 to 2013 cell *b)* classified as "no-urban" shifts to a low degree of fragmentation following the installation of 4 wind turbines. The same cell in 2018 assumes a "not fragmented" degree following the installation of new wind turbines in proximity of the existing ones that lead to the formation of a single aggregate. The opposite process occurs for the cell *a)* which from a "not fragmented" degree in 2008, following the installation of other wind turbines distant from the existing ones, assumes a "low" fragmentation degree in 2018. In the first case there is a trend to compacting the existing aggregates while in the second case there is a trend to fragment them. Therefore: RES_w installed away from existing ones generate fragmentation and thus correspond to the sprinkling phenomenon. In contrast, wind turbines installed close to existing ones correspond to low degrees of fragmentation or better “not fragmented” situation, i.e., the compaction phenomenon.

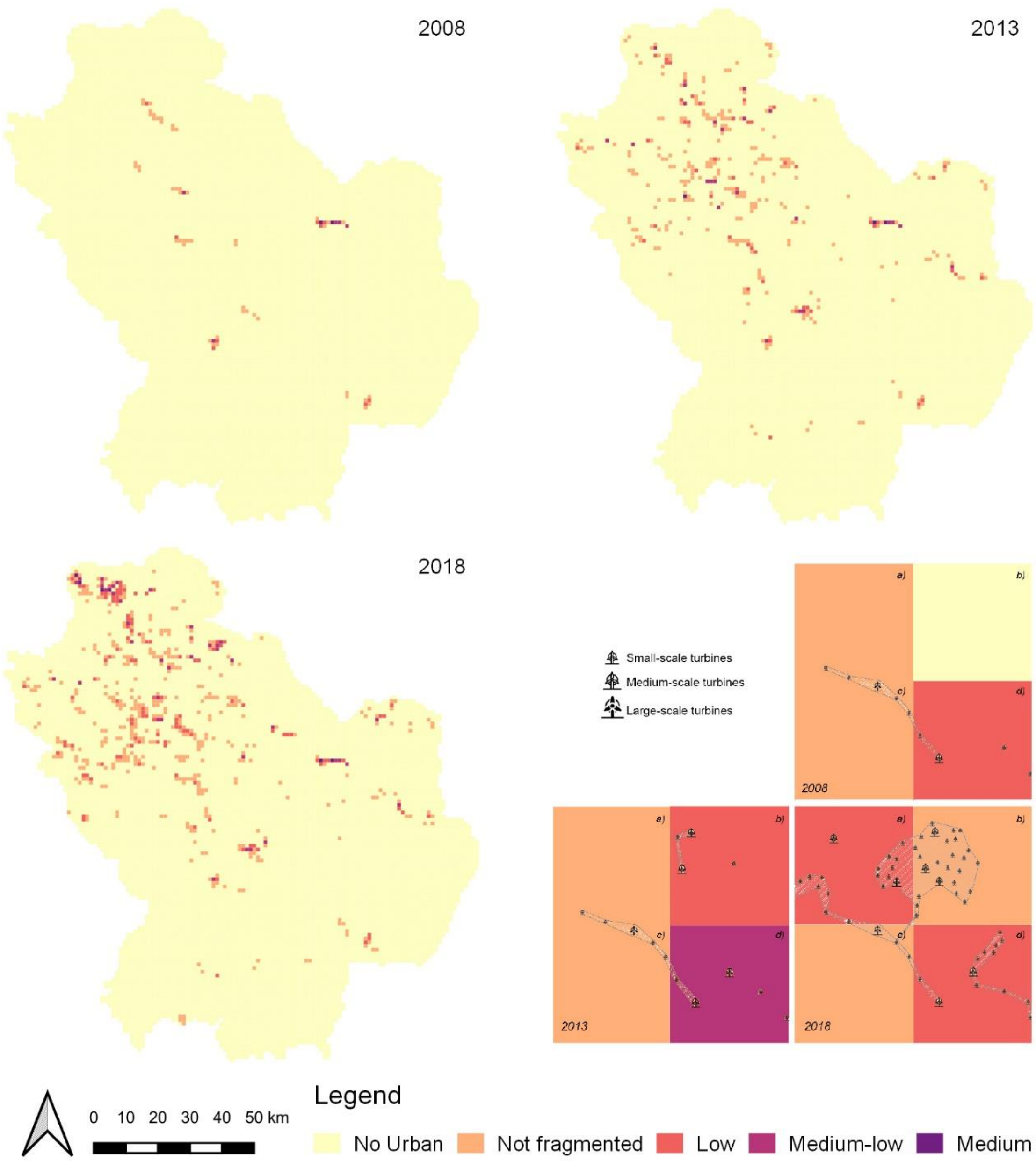


Fig. 33 Three maps of the fragmentation degree at the regional level for the years 2008, 2013 and 2018 with a 1 km square grid. Bottom right a sample of 4 grid quadrants representing different expansion dynamics (SPX_RES_w).

The three maps in the Fig. 33 show the fragmentation degree for each cell. Due in part to the minimum wind turbine distance imposed by PIEAR, the maximum degree of fragmentation achieved is “Medium”. No cells with “Medium-high” and “High” fragmentation degree resulted. However, it cannot be considered a positive result since from 2008 to 2018 wind energy plants have spread over the territory going to fragment (although not to a high level) additional patches of land.

It is evident how from 2008 to 2018 the fragmented cells increase, demonstrating that in addition to the huge number of wind turbines, the sprinkling generated by them also increases. Between 2008 and 2013 the “not-fragmented” cells (those containing a single aggregate) increase by almost 5 times and in 2018 the cells with low fragmentation correspond to about 10 times those of 2008. The only areas that are RES_w free in 2018 concern the southern part of the region where there are two National Parks and a large forested area in the southern part of the Vulture area.

In order to evaluate the contribution of the wind turbine installation on the urban sprinkling already produced by the Build layer, the SPX index was calculated considering RES_w and Build layers jointly. The data was then compared with the SPX_Build_1 index and reported in the graphs in the Fig. 34 divided by the seven fragmentation degrees. The three graphs (Fig. 34) are representative of the number of 1 sq km grid cells for each fragmentation degree at years 2008, 2013, and 2018 from left to right. The outside circle represents the SPX_Build_1 plus SPX_RES_w values while the inside circle represents the SPX_Build_1 values obtained in section 4.3.1.

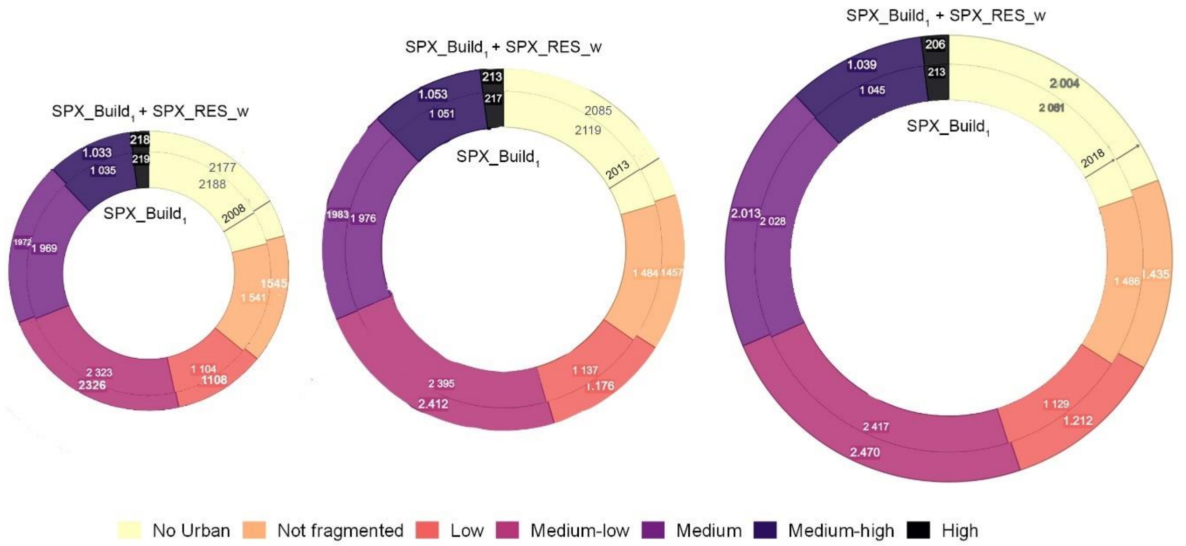


Fig. 34 Comparison between the SPX_Build1 and SPX_Build_1 plus SPX_RES_w at year 2008, 2013 and 2018.

Considering the changes in the spatial distribution of the fragmentation degree between 2008 and 2018, looking at the settlement system consisting of both Build and RES_w layers, there is a slight contraction of the highest fragmentation classes in favor of cells classified as "Not fragmented" or low and medium-low fragmentation degree. From 2008 to 2018, the inclusion of RES_w in the SPX_Build_1 results in an 8% decrease in non-urban cells, i.e., those considered free of artificial surfaces. At the same time, low to medium fragmentation cells increase by 18%. Fragmentation trends, appear almost stationary when looking at the entire period. The exceptions are the "Low" and "Medium-Low" grades, which increase by 10% in 2018 compared to SPX_build_1.

The increase in cells with low to medium fragmentation is significant of the ways in which the development of RES_w technologies has led to land transformation. Indeed, in the 2008, the most advantageous areas were "colonized" with the large-scale turbines. Having reached (quickly) the production limit set by PIEAR for this type of installation, wind farms were densely populated with smaller turbines (medium and small-scale turbines).

In order to highlight how the process of territorial fragmentation occurred in recent years is due more to the installation of new wind turbines than to the construction of new buildings, the new areas occupied by the two components of the settlement system analyzed in the three temporal phases have been compared. The graph (Fig. 35) shows for the years 2008, 2013 and 2018 the amount of area expressed in square kilometers occupied by the new Builds layer (considering them as aggregated at 50 meters) and the RES_w layer (considering the buffer radius aggregated with the distance of 250 meters).

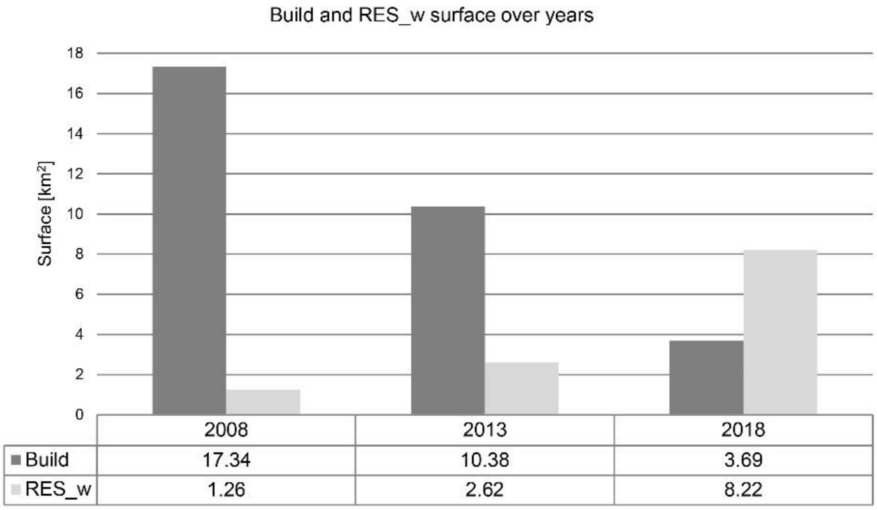


Fig. 35 Land take deriving from Build layer aggregates and RES_w aggregates over the years.

From 2008 to 2018, the land take trend has completely reversed. In 2008, the new surface occupied by Build layer (93%) is significantly larger than that of RES_w (7%). In 2013, the area of wind farms began to grow significantly, involving 20% of land transformation. The gradual decrease in territorial transformation due to the Build layer leads to a total reversal of the trend in the last period. In the 2018, in fact, the area modified by new RES_w is more than double the area sealed due to new construction. The installation of new wind turbines contributes to 69% of the territorial transformations for a total of 12 sq. km.

4.3.3. Sprinkling index for all the settlement system components

In this section the SPX_tot results are presented. SPX was calculated considering all components of the settlement system for 6 temporal phases, specifically: 1950, 1989 and 1998 with Build layer and Hw layer, respectively for each year; 2008 with Build layer of 2006 and Energy layer of 2008; 2013 and 2018 with Build layer and Energy layer respectively for each year. Build layer and RES_w were considered in their aggregate form as in previous analyses. The SPX index was applied on the basis of the same 1 sq. km grid used for the Build layer and RES_w.

In this case, the change in the SPX index was investigated in order to identify the main dynamics of expansion: fragmentation or compaction (densification). In order to compare the changes that occurred in the different temporal intervals, the distribution of the data sets was analyzed on a graph (Fig. 36) that represents the observation frequency for each of the values assumed by the SPX index. Looking at the values distribution over the years, some evidences emerge immediately. Over the entire period considered (1950-2018), the fragmentation degree increases overall, leading to an increase in the median value of SPX from 20.3 to 31.4 with a subsequent increase in territorial fragmentation.

Considering all the changes that have taken place during the entire period, it is possible to distinguish the areas in which the two prevailing transformation dynamics (fragmentation or compaction) have taken place. The most evident compactation phenomena occurred along the Apennine mountains and in correspondence with the principal settlements. Fragmentation, on the other hand, is prevalent along the Bradano valley and in the eastern part of the region. The fragmentation observed along the whole Ionian coast, where larger municipalities are located, is particularly intense.

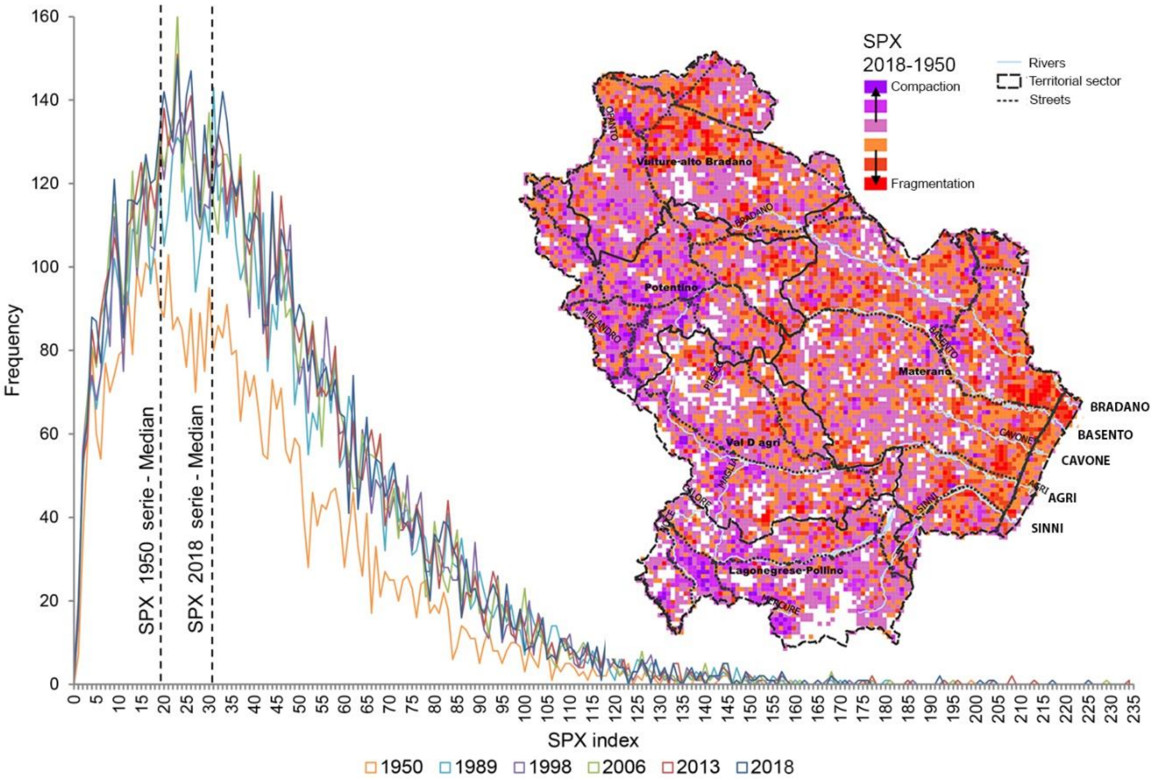


Fig. 36 Fragmentation vs Compaction: Anthropic settlement analysis for Basilicata region

The second observation regards the most relevant differences that come about in the first temporal phase (1950-1989). The spatial distribution of the SPX index suggests different dynamics that characterize the evolution of the anthropic system. In accordance with the well-known features that characterize the economic upswing period, the maps in Fig. 37 show a marked increase in fragmentation along the Ionian coast due to an increase in demand for settlement and the consequent construction of new housing. The effects of the intense industrialization that took place in this first period and favoured the main road networks along the major river valleys for the realization of productive hubs, is also clearly visible. The anthropization phenomenon along the Basento Valley, where an important industrial center arose after the IIWW, is an obvious example. A contribution to the high degree of fragmentation in the middle and lower Basento Valley also comes from the construction of the first infrastructure to support the oil industry.

Between 1989 and 1998 the building activity proceeded. This indicates that in many cases the fragmentation index decreased because new buildings extended pre-existing aggregates until, in some cases, an urban settlement combined. In the northern part of the region there is an even greater increase in the number of buildings, partly due to the abandonment of the historical centers that were heavily damaged in the earthquake of 1980 and the consequent construction of new residential buildings.

The extraction areas (Hw layer) previously identified along the Basento Valley are the subject of new drillings that contribute to the increase of the SPX index even in previously natural or semi-natural areas.

During the same period, relevant territorial transformations took place in the Agri Valley sector, where an area of about 30 ha was occupied by infrastructures connected to new hydrocarbon wells. In most cases, these transformations take place within a rather fragmented rural context which, due to the significant size of these sealed surfaces and infrastructures, becomes more compact. When considering impacts induced by the realization of such constructions and infrastructures on the territory, it is necessary to make a clarification, due to the fact that habitat fragmentation resulting from the construction of the road network is not considered in the SPX index.

As a matter of fact, in some cases, drilling plants have been built in a natural context in which, in the absence of previously anthropized surfaces, the building activity corresponding to a single core and/or aggregate results in a SPX value equal to zero. However, in order to assess the total degree of landscape fragmentation, the road contribution would be significant.

There was no substantial change in the regional context in the period 1998-2006. The dynamics described above do not lead to an increase in the SPX in the Agri Valley area despite land take due to Hw increased more than 10 ha. A significant increase in the fragmentation degree can be observed along the Ionian coast, where significant investments in the tourism and hospitality sectors have led to the development of new structures, inserted within the agricultural context.

From 2008 to 2013 considerable transformations can be noted in the nearby Matera and Vulture-Alto Bradano areas. The Matera municipality shows an increase in the surface occupied by Build_r from 1125 ha to over 1341 ha, in addition to about 63 ha covered by RES_s and about 3 ha due to the RES_w. This leads to a significant increase in the fragmentation index.

During the last five years (2013-2018), changes in fragmentation are almost entirely attributable to the widespread installation of new RES systems. This is particularly noticeable in the northern part of the region, where there is a much larger increase in the industrial-productive areas than in others. A similar situation can be observed in the Vulture Alto-Bradano sector, specifically in the Banzi municipality, where the installation of 26 new wind turbines lead to a significant increase in territorial fragmentation.

Analyzing the regional context, it is possible to observe an increase in anthropic settlements along the Ionian strip (Materano territorial sector) with a relevant increase in new buildings. These new buildings, driven by the development of the tourism sector, involve different variations in terms of territorial fragmentation. Another special case is that of the Matera municipality which, following its designation as the European Capital of Culture in 2019, has undergone a significant development in terms of tourism and accommodation facilities. This has led to an increase in urban areas of more than 80 ha, to be added to a further 3 ha for new RES_w. While new buildings are located close to the existing settlement and thus contribute to increasing the degree of compaction, wind turbines located in the peripheral areas of the city center, lead to a gain in fragmentation.

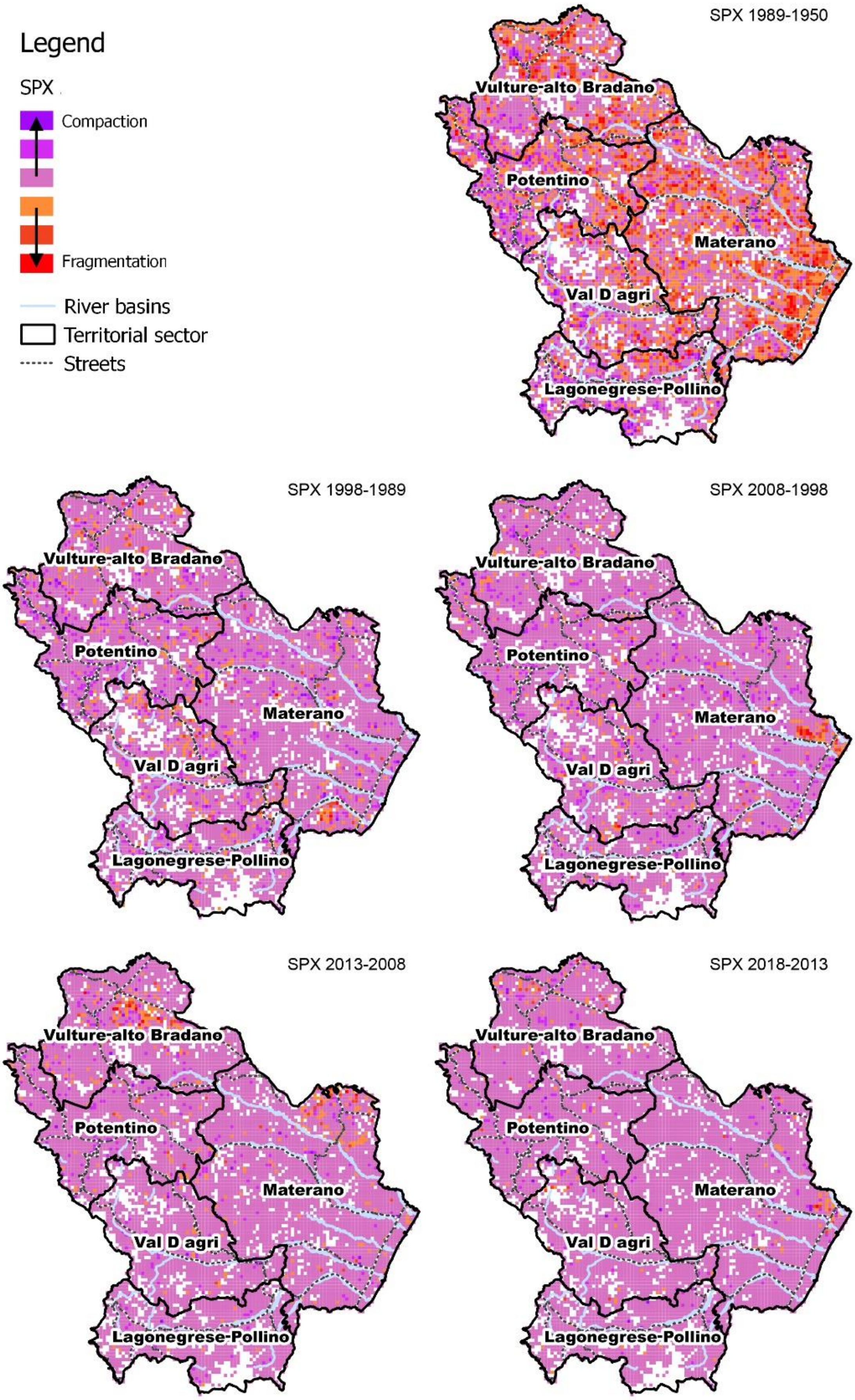


Fig. 37 SPX_tot index variation over the temporal phases considered

4.3.4. Infrastructures fragmentation index - IFI

According to Eq b, the IFI index was calculated considering as the territorial reference unit: IFI_1 the same grid of 1 sq. km used for Build and RES_w and IFI_m based on the administrative limits of the 131 municipalities of the Basilicata region. IFI_1 returns a value for each grid cell that has been expressed in degree of infrastructure fragmentation. For both spatial units of reference, the IFI index was transformed into the fragmentation degree from high to low. As the IFI index increases from time t_0 to time t_1, the degree of fragmentation from infrastructure increases. The change in the IFI index can only be positive since the construction of new linear road infrastructure can only increase the degree of split patches in a given reference area. Fig. 38 shows the results of the IFI_1 index. On the top left side, the current situation is shown, that is, the fragmentation degree from infrastructure to the year 2018 from low to high. It can be seen that the most fragmented areas correspond to: the area around the cities of Matera and Potenza, the two provincial capitals; the municipality of Melfi, which is important from an industrial point of view and also in recent years has seen much of its agricultural land taken away for the construction of new road infrastructure to serve RES systems; the Ionian coast that has undergone since 1989 great transformations following the development of the tertiary sector concerning agriculture and tourism.

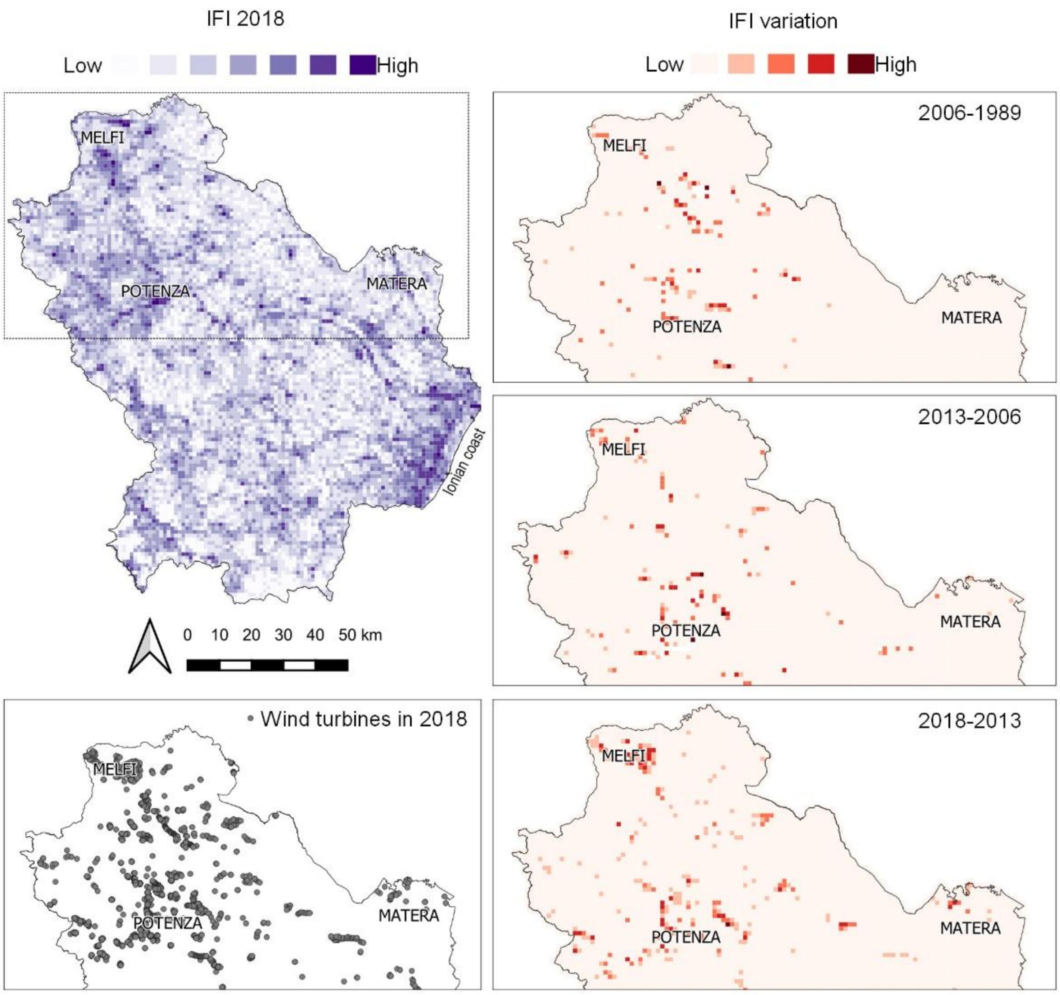


Fig. 38 Maps of the IFI index at year 2018 and three zoom maps of IFI variation between the year 1989-2006, 2006-2013 and 2013-2018 (IFI_1). The sample map with wind turbines location at year 2018 is on bottom left.

In order to understand the intensity of infrastructure fragmentation, it is possible to read the data on cells classified as “no-urban”, in other words, non-artificial, which in 2018 are only 1.67% of the total, compared to 19.85% of the non-urban cells calculated with the SPX_build_1 index. Comparing the IFI_1 “no-urban” grid cells with the corresponding SPX_Build_1 cells, it emerges that 166 cells are classified as “no-urban” in both indices while 8 (corresponding to 8 sq. km) are classified as “no-urban” in IFI_1 and as “not fragmented” (that means compact) in the SPX_Build_1 index. These same cells are classified as “no-urban” (i.e., non-artificial and not occupied by RES_w) in the SPX_RES_w index. This is a demonstration that compaction produces less costs associated with new infrastructure construction than fragmentation dynamic.

On the right of Fig. 38 are reported, for reading simplicity, three maps of the IFI index variation concerning only the northern part of the Basilicata region in which the greatest changes have occurred. Between 1989 and 2006 there is the lowest variation in infrastructure fragmentation, 1.81% of the total cells see their IFI index increase due to the construction of new road infrastructure. Comparing the cells that have undergone an increase in the IFI index with the SPX_build_1 variation in the same cells, we note that: 29% of these cells have undergone an increase in fragmentation by buildings, 22%, compaction and for the remaining 38% an increase in fragmentation caused by infrastructures has been followed by a null variation of the SPX_Build_1 index. This means that between 1989 and 2006 fragmentation from infrastructures was generated by the construction of new roads in cells not interested by the construction of new buildings but evidently to serve cells far from existing ones where new expansion occurred (principally in fragmented manner).

In the next two phases, from 2006 to 2018, the IFI varies by 2.33% and 4.48% between 2006-2013 and 2013-2018, respectively. The year 2006 is indicative of the period when RES_w facilities began to be installed. In fact, at the bottom left of Fig. 38 there is a map of the wind turbine locations in 2018. It is evident that in the vicinity of the largest number of wind turbines, the degree of fragmentation increased between 2006 and 2018.

Fig. 39 shows the IFI_m index difference maps for the periods: 2006-1989, 2013-2006, and 2018-2006. In order to highlight how the process of spatial fragmentation caused by infrastructures in the last decade is more attributable to the installation of new wind turbines, a comparison is proposed with the map at the bottom right (Fig. 39). In addition to the three maps of the IFI index variation, the map of Basilicata representing the number of wind turbines for each municipality in the year 2018 is presented. This allows us to compare the two data; we can see that, in fact, the municipalities with the highest number of turbines have undergone high or at least medium changes in fragmentation. Taking for example the Potenza municipality, this in the face of a large number of wind turbines installation (the largest of all Basilicata region, 297), sees an increase in the degree of fragmentation from infrastructure.

The municipality of Tito, in the southwest of the municipality of Potenza that has a small number of wind turbines (8) has a large variation in the IFI index in the time interval between 2013 and 2006. Considering the small number of wind turbines, the construction of new roads that contributed to the growth in the fragmentation index can be attributed to the construction of new buildings. Comparing this result with the maps in Fig. 30 from 2006 and 2013, we note that the municipality went from "medium" to "medium-low" fragmentation. This shows that the municipality has been affected by a transformation related to

the construction of new buildings that has led to a kind of compaction of existing nuclei, which, however, in turn have led to the construction of new road infrastructure that has generated fragmentation. At the same time, the municipality of Melfi (identified with the number 161 for wind turbines number) undergoes an “medium-high” increase in the IFI index which is completely attributable to the RES_w layer. In fact, between 1989 and 2018 the same municipality does not experience any change in the SPX_m index, no obvious transformation due to the construction of new buildings (see Fig. 30 for comparison).
In the last period (208-2013), 61% of municipalities where wind turbines have been installed (70 municipalities in total) experienced an increase in fragmentation by road infrastructure. This leads to the assertion that the process of spatial fragmentation, which has occurred in the last decade, is largely attributable to the installation of new wind turbines.

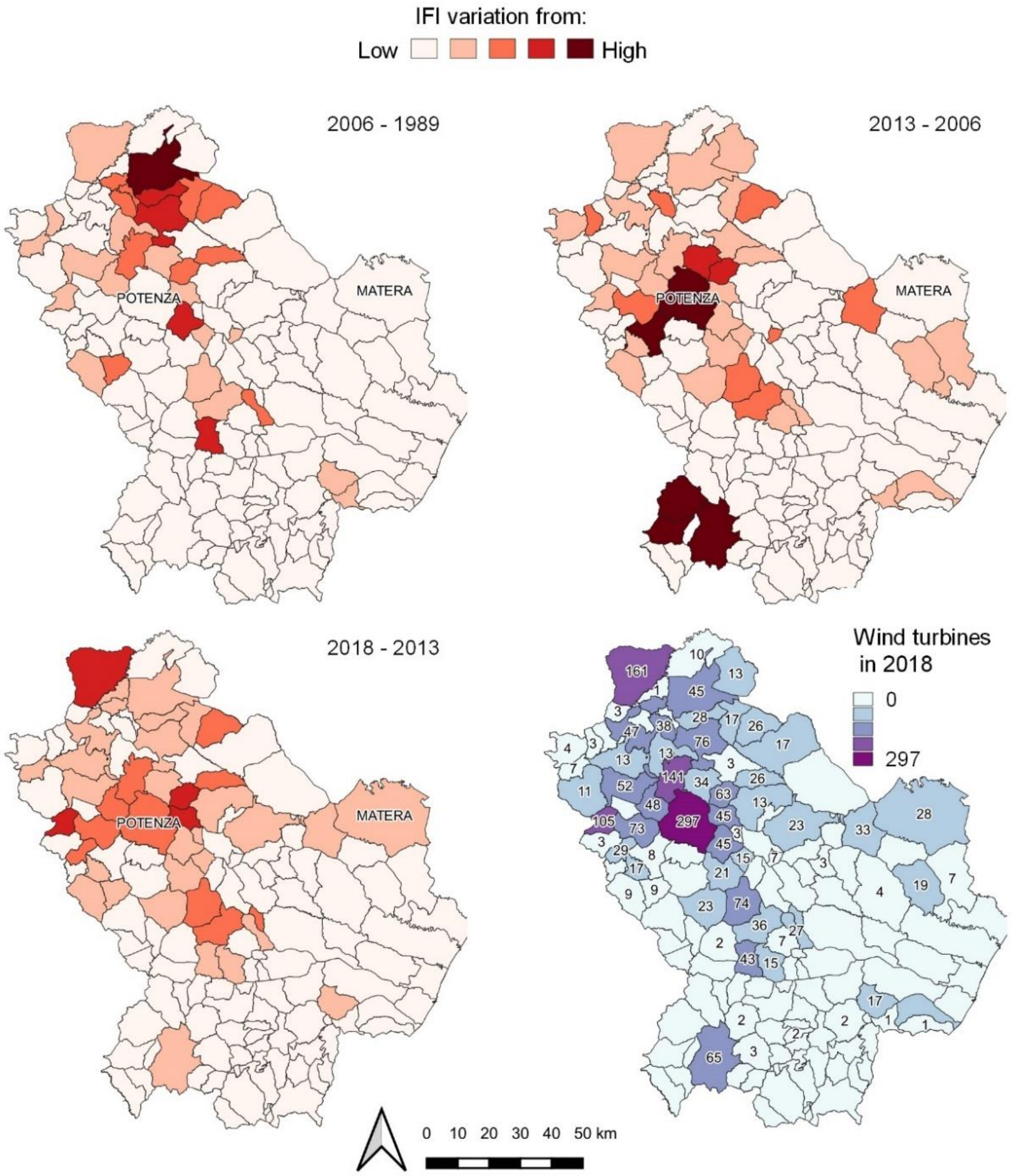


Fig. 39 Maps of the variation in the IFI index between the years 1989-2006, 2006-2013, and 2013-2018 (IFI_m). The last map represents the number of wind turbines for each municipality at year 2018.

4.3.5. Landscape fragmentation

In order to analyze the landscape fragmentation and to have an overview of the structural characteristics of the whole territory of Basilicata region, all the components of the settlement system used in the previous paragraphs, have been integrated into the CLC maps at the years 1990, 2000, 2012 and 2018 (for details see section 4.2.1 - *Land cover layer*). This section presents the results of the landscape metrics and diversity indices calculated for each temporal phase. The table (Tab iii) containing the detail of all indices can be found in Appendix B - Tables.

The land cover index is expressed in square kilometers. The territory of the Basilicata region is mostly covered by agricultural soils, in particular intensive agriculture, and forests. The temporal analysis shows a loss of land between 1990 and 2018 for 123 sq. km. of forests, 276 sq. km. for grassland, and 280 sq. km. for the land cover class concerning extensive agriculture. On the contrary, the land cover classes concerning intensive agriculture, bare soils and arbustive soils, and the most anthropized classes such as residential buildings and industrial and commercial buildings are increasing. There is also an increase in the areas occupied by RES plants that, absent in the years 1990 and 2000, reach a covered area of 6 square kilometers in 2018. Fig. 40 shows the gains and losses of land in square km for each land cover class between 1990-2000, 2000-2012, and 2012-2018. The increase in intensive agriculture affects little fragmentation but much environmental and economic sustainability since it is applied more broadly than extensive agriculture and involves the use of fertilizers, fungicides, and pesticides that are considered pollutants.

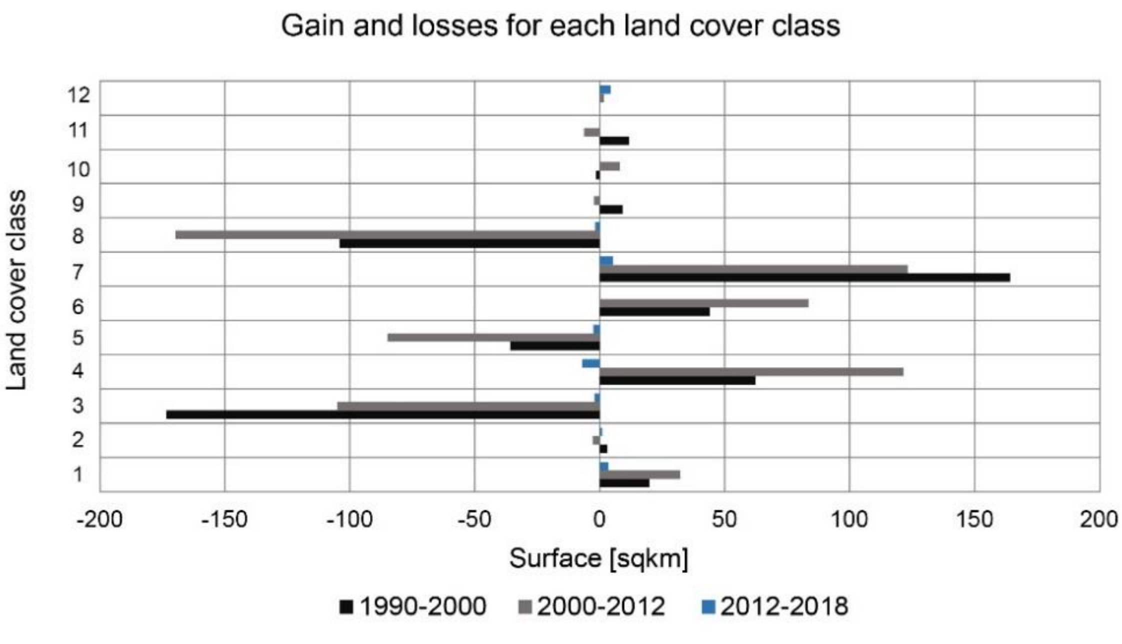


Fig. 40 Gains and losses for each land cover class from 1990 to 2018.

In Fig. 41 the results of the landscape proportion index are shown in the ring graph where each concentric circle represents the time phase analyzed and respectively from the inside out: 1990, 2000, 2012 and 2018. It is evident that as the proportions of extensive agriculture, forests and grassland decrease, those of intensive agriculture, bare soils and arbustive soils increase. The class of residential buildings also increases, although slightly relative to the other land cover classes.

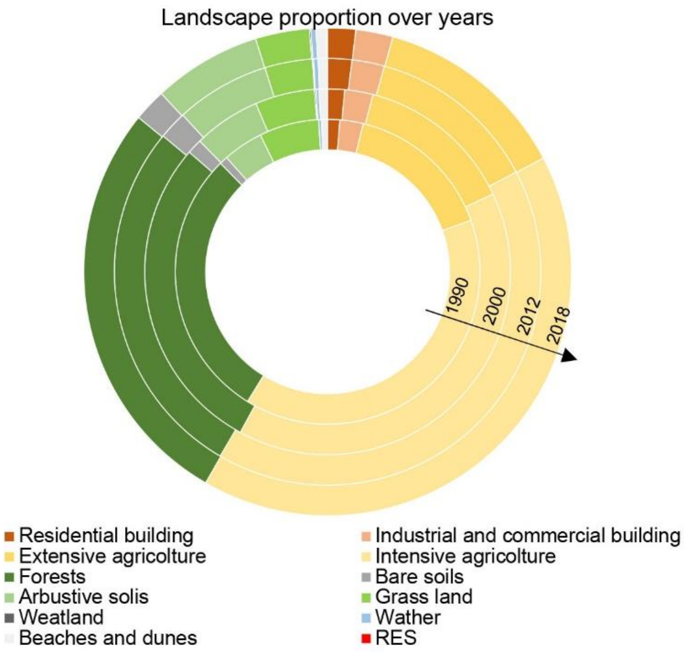


Fig. 41 Ring graph of landscape proportion index over temporal phases analyzed.

Edge length index results are shown in km. Representing the border length of the patches, the increase of this index over the years translates into an increase in landscape fragmentation. The index increases for the anthropic surfaces, i.e., the CLC classes with code 1, 2 and 12, which means that the new expansions have occurred in a fragmented manner going to occupy other patches separate from the existing ones. Because the patches are obviously enlarged, the edge length index concerning intensive agriculture and the grassland class are decreasing. The edge density index, like length density index, undergoes small increases during the various temporal phases, especially for the anthropic classes.

Fig. 42 shows the results graph of the Largest patch index, on the x-axis the temporal phases considered and on the y-axis the index values on a base-10 logarithmic scale; each line represents the index trend for a specific land cover class. The index represents the percent extent of the area of the largest patch, of a given class. The maximum value (100) indicates that the entire study area is covered by a single patch. In a temporal analysis, as the index decreases, the degree of fragmentation increases because it means that the analyzed path decreases in size (fragmenting). The index increase means the compaction of two or more patches. The analysis returns very high values for intensive agriculture, which increases in the first period (1990-2000) against a small decrease in extensive agriculture, after which it continues to grow. Intensive agriculture is therefore characterized by very large patches that over time are tending towards compaction, subtracting patches from other categories such as extensive agriculture and arbustve soils. The graph also shows the very high value of the forest index which, in 2018 has the more largest path equal to 176 sqkm.

The values of the indices concerning the anthropic classes (codes 1, 2 and 12) are very low (between 0.06 and 0.23) demonstrating that they are composed by patches of small dimensions (attributable to the phenomenon of sprinkling). Their decrease over the years - even if small compared to that of intensive agriculture - translates into an increase in fragmentation dynamic.

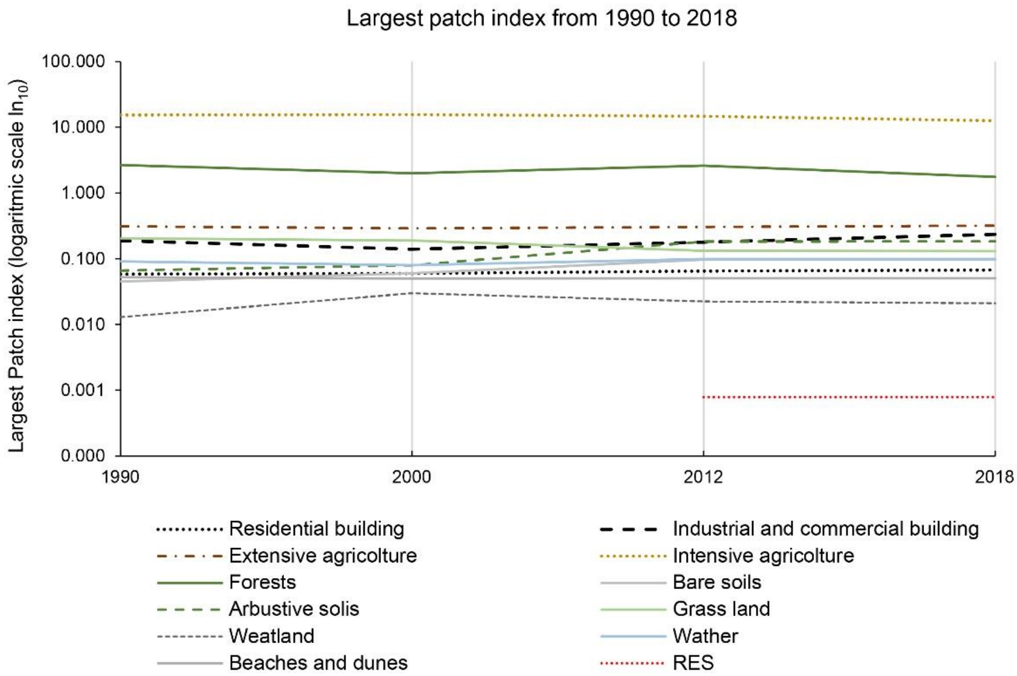


Fig. 42 Largest patch index from 1990 to 2018 for each land cover class.

The high value of the splitting index depends on the dimensions of the patches of the various land cover classes. The more a class is constituted by small patches, the more this index increases. In fact, the highest values are recorded for the anthropic classes concerning RES, residential, industrial and commercial buildings, while the lowest values are for intensive agriculture and forests.

Analyzing the number of patches highlights how the number of patches for each year analyzed is constantly increasing. Between 1990 and 2018 the total number of patches increased by about 30,000 units, so the territory is increasingly fragmented into smaller patches. It is noticeable that the number of patches is high for antropic land cover classes such as those of buildings and RES.

Diversity indices return an overview of fragmentation across the study area and considering all land cover classes. The graph in Fig. 43 shows on the x-axis the time steps analyzed, on the main y-axis (the left one) the values of the SI and E_V indices and on the secondary y-axis (the right one) the values of the SH index.

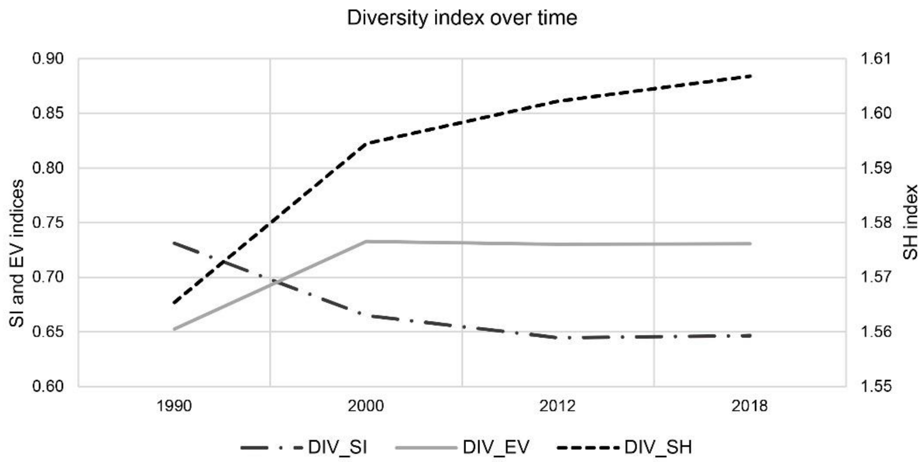


Fig. 43 Comparison between diversity indices between the considered years.

Changes in the indices result in an increase in fragmentation. The variations are very small since there are high size patches such as intensive agriculture that greatly affect the final result. E_v and SI whose ranges are between 0 and 1 are also representative of a homogeneous distribution of patches on the territory.

4.4. Discussion: the fragmentation dimension of Basilicata region

In this chapter, the evolution of the settlement system in the Basilicata region was analyzed, considering as drivers of land take and fragmentation not only the traditional components such as residential buildings, industrial buildings and road infrastructures, but also new components that until now have not been included in the traditional planning. The transformations of the last decades (since 2008) related to the installation of renewable energy systems have been strongly influenced by the development policies of the energy sector. The results obtained provide a generally fragmented picture of the study area. The sprinkling index unlike other fragmentation indices allows for the evaluation of the distance between aggregates along with their surface areas and number. The grid methods for the calculation of the SPX index allow the measurement of the urban sprinkling phenomenon; however, the quantification itself cannot be considered univocal, as the translation of the grid would be necessary to obtain different results. Nevertheless, using the same grid for different components of the settlement system and for other fragmentation indexes such as the IFI, the results become comparable and make it possible to identify the major causes of the fragmentation processes that have occurred.

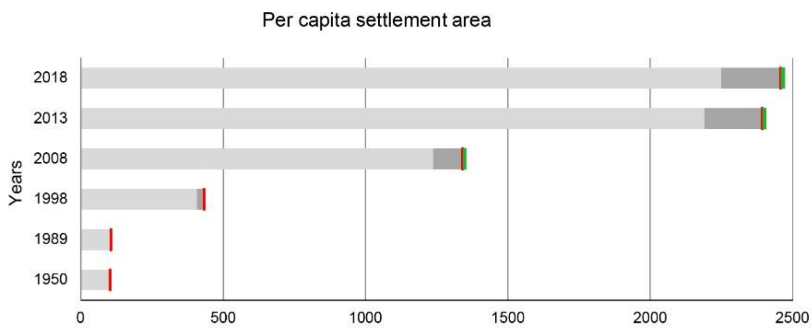
The calculation of the SPX index on the basis of municipal boundaries in turn, provides an assessment of the urban sprinkling on a municipal scale, which is the same scale used by decision-makers. However, it does not consider all contouring conditions (which would explain the distance of a settlement from the core of its municipality) and the possible dependence on the size and shape of the area of a municipality (since the value of the SPX index is a function of the distance between urban aggregates). The two methods proposed to calculate the SPX_Build index, despite the different scales of application, produced very similar results. The regional territory was characterized, for the most part, by a fragmentation degree ranging from “medium”, to “medium-high”. The SPX_Build results from 1950 to 2000 show an ever increasing trend in the number of urban aggregates. This involves, on one side, a decrease in aggregate average area, and on the other, their increase in number. The whole territory has been subjected to different fragmentation levels of the settlement system. Even if the households’ motivations in creating new buildings for residential purposes was not the focus of this research, we may affirm that the progressive phenomena of depopulation and abandonment of historical settlements is a consequence of a social behavior oriented to use land properties for residential scope, more than for productive activities. The consequent urban expansion occurred with a pulverized growth model and this fragmented territorial system structure increased land take and has had a significant environmental impact [37,82,196–198].

The urban sprinkling phenomenon in the Basilicata territorial context has mainly affected rural areas that are progressively undergoing irreversible transformations. The results discussed are representative of regions with low settlement density, where a weak presence of resident population puts the impacts of the territory in the background. In fact, the results of the index SPX_RES and SPX_tot show that from 2008 in the face of a population decrease, expansions due to the construction of new buildings have been gradually replaced by land take for the installation of RES and industrial plants.

Considering wind turbines as a new component of the territorial settlement, a high degree of fragmentation has emerged both with the SPX and IFI indices; several roads have been built to serve the new renewable energy plants. The Basilicata region, is in the first position of the Italian regional ranking for the number of wind turbines installed. Moreover, RES_w are not considered a component of spatial transformation according to the current urban planning. Therefore, their spatial distribution took place without any formal spatial regime or arrangement. This is the demonstration of the current weakness of spatial planning (especially in Italy), where planning tools and urban laws are not able to keep up with the rapid changes in the anthropization categories (produced by sectoral policies) and therefore, are not suitable to support decision making towards an effective and sustainable development scenario.

Basically, the only decision-making level for land transformation is represented by municipal plans; however, our results show that this level, in accordance with the current planning tools, failed to perform this function adequately, since they are not updated in accordance with the new planning targets: land take, conservation of ecosystem services, adaptation to climate change and quality of urban life. The case study of the Basilicata region highlighted how the territorial transformation phenomena that are not linked to the need for residential settlement or industrial development (the categories of the traditional planning system) but promote new anthropic installations (i.e RES) can significantly alter the low-density settlement landscape thereby contributing to increasing the degree of territorial fragmentation. The weakness of the planning framework as well as of the high percentage of territory not regulated by any kind of plan [60], had already led to a high level of fragmentation of the rural environment in the Basilicata region, as a result of a development process that has already taken place in the absence of a real settlement need.

The per capita settlement area, in this regard, as a good indicator to represent the inefficiency of the plan (Fig. 44).



	1950	1989	1998	2008	2013	2018
Build_r + Build_c	99.85	102.70	406.84	1236.79	2189.35	2248.34
Build_i	2.49	2.57	24.46	102.99	202.69	208.15
Hw	0.01	0.39	0.86	1.98	2.00	2.05
RES	0.00	0.00	0.00	10.15	12.24	13.87
TOT	102.36	105.65	432.16	1351.91	2406.28	2472.42

Surface per capita [mq/inh]

Fig. 44 Per capita settlement area variation over the period

The total area pro capita transformed varies from about 102 sqm/inh to over 2470 sqm/inh over the entire period considered. This growth is due to both an increase in the number of buildings and a decrease in the population from the ‘70s onwards. This has led to landscape and habitat fragmentation, inducing the loss of aesthetic, ecological and perceptive values in a hardly reversible way.

The settlement, intended in its different forms and manifestations (built-up areas, infrastructures, productive and agricultural spaces), is the first responsible of the environmental fragmentation and its characteristics can be explored and returned through specific indexes. Some parameters are part of the urban descriptive tradition, while others are of recent elaboration and more related to the aspect of interference between settlement systems and the effects caused on the integrity of ecosystems.

In order to achieve optimal levels of planning and land management, it is essential to select and use, from the outset, appropriate indicators that ensure the establishment of a cognitive basis for the tools of land management.

5. Modeling Urban Sprinkling with Cellular Automata[3]

"We cannot predict the future, but we can prepare for it"

From the results obtained until now, it emerges that Basilicata is a region with a low settlement density, whose transformation dynamics are in line with those of urban sprinkling and is characterized by a medium-high degree of fragmentation. In this regard, it is essential to model future scenarios of urban expansion in order to propose a valid tool to support the decision-making system in the management of urban transformation. In this chapter, an analysis of urban expansion through a multi-density approach is proposed in the context of the Basilicata region where the imbalance between urban expansion and population decline is a relevant phenomenon. Cellular automata and multinomial logistic regression will be used to analyze the spatio-temporal relationships between urban expansion and built-up causal factors. The results of the 2030 urban sprinkling projection will show that new urban expansion involves low-density classes (again generating urban sprinkling).

The results presented up to now have described a region at low settlement density characterized by the dynamics of urban sprinkling in which the settlement component concerning residential, industrial and commercial buildings has played a relevant role especially from the 50's to the first decade of 2000.
At this point it is important to model future scenarios of urban sprinkling in order to understand which are the main physical and social factors (drivers) that influence it and to predict the amount, geographically recognizable, of future land take.
There are several answers to the question: why simulate future urban expansion scenarios? Among a variety of possible answers, some are: (i) to make better land management decisions, (ii) to implement environmental agreements (iii) to distinguish between what we know and what we don't know about land cover changes, (iv) to increase knowledge about land cover changes, (v) to know the implications of our assumptions, (vi) to be able to predict future expansions with a measured level of accuracy, (vii) to be able to predict with a high level of accuracy. In the case study considered, surely modeling future urban sprinkling scenarios can help to establish off limits areas for transformation and control the social costs that the population is suffering due to the urban sprinkling phenomenon, as demonstrated in Manganelli et al. [22], in fact, social costs increase as urban sprinkling increases.

[3] This chapter is extracted from: Saganeiti, Lucia, Mustafà, A., Teller, J., & Murgante, B. (2020). "**Modeling urban sprinkling with cellular automata.**" *Sustainable Cities and Society, 102586.* DOI: https://doi.org/10.1016/j.scs.2020.102586

As anticipate in the previous chapter, on the Italian territory, urban sprinkling is usually associated with weak urban planning. In some cases, it is the consequence of abusive initiatives, encouraged by amnesties for the violation of building regulations. Uncontrolled, poorly managed and fragmented urban transformation generates an economic and social impact on the population also defined as a social cost. The social cost includes direct costs arising from the construction of new roads, new infrastructure services and indirect costs arising from health costs due to increased pollution due to increased travel, costs due to loss of landscape quality and other costs associated with the daily life of the local population [38,127,128].
A fundamental prerequisite for developing or applying an urban transformation prediction model is certainly the knowledge of the factors that influence the process, i.e. the causative factors (drivers). Many studies [54,199–202] are dedicated to the analysis of the drivers that regulate the dynamics of transformation of a territory, i.e. the processes of urbanization. The processes of expansion are usually influenced by geophysical, socio-economic and legislative conditions. Most research shows that economic factors, including population growth, income, value of agricultural land, are of primary importance in setting the rules for urban expansion [203,204]. Indeed, urban prediction models are generally applied in contexts where the population growth rate is positive and settlement density is relatively high. Rienow et al. [54], in contrast, analyses a rural context with scattered settlements and a negative demographic trend in a German region.
Land use models allow to project and simulate future urban patterns in order to act on the dynamics and mechanisms of urban expansion [205]. Urban land use change models are generally analyzed and applied to provide a decision support to policy makers in the implementation of new urbanization plans [199,206,207]. Furthermore, these models can support planning policies such as flood risk mitigation [208], regulation of climate change and the provision of ecosystem services [209] and the development of scenarios for environmental impact assessment [210]. In this study, our focus is to cross the literature gap concerning the correlation between demographic trends and urban expansion in order to arrive at the conclusion that a predictive model can be used to control urban transformations where they are not necessary and to preserve those areas with a particular environmental value.
In this research, we have applied a modeling approach that integrates multinomial logistic regression (MLR) and cellular automata (CA) to analyze and project urban sprinkling. The model was proposed by Mustafa et al. 2018 [211] and used to simulate urbanization scenarios in Belgium.
In the case study of the Basilicata region, a simulation and projection model of urban sprawl will be used, based on a multi-density approach (4 urban density classes). This approach appears to be fundamental and novel for a context governed by urban sprinkling or an urban expansion in the absence of population growth. For urban expansion modeling, therefore, built-up density maps were generated on the basis of three regional building datasets (1989, 1998 and 2013) with four density classes: no built up, low density, medium density and high density and used for the calibration, validation, and simulation phases. The transition probability for the calibration (1989-1998) has been calculated with MLR for the built-up causative factors and with multi-objective genetic algorithm (MOGA) for CA neighborhood interactions. Among the causative factors considered are those concerning the physical, socio-economic, proximity and constraints factors. The calibrated parameters were used for the simulation of

the 2013 map which was compared with the actual map of 2013 (validation). The final objective is to simulate business as usual urban pattern in 2030.

5.1. Data source and processing

5.1.1. Building density maps

In order to generate built-up density maps, we used the Build layer of the section 4.2.1 in a vector format for the year 1989, 1998 and 2013. These three vector maps have then been rasterized at a 2x2 m pixel resolution. The rasterized maps have been aggregated to a 100x100 pixel resolution in which every pixel has a range density values from 0 to 2500 (counting the 2x2 m pixels within each 100x100 m pixel). We then classified the urban density continuum into four classes: non built-up, low density, medium density and high density. The geometric classification was used to identify the ranges between the density classes. Table 8 summarizes the ranges of values for the building density classes. The density 18.75 is the limit below which the pixel is considered "no-built up". This value corresponds to a building of 75 square meters: the minimum size (established by Italian legislation) for a building to be declared habitable by 4 people.

Table 8 Buildings density classes.

Class	*Density classes*	*Density value*	*Built surface/ha*	*Coverage ratio [%]*	*% of cells in the study area (year 1989)*
No-built up	0	from 0 to 18.74	Less than 75 sqm	-	93.62
Low density	1	from 18.75 to 54	Less than 220 sqm	from 0.75 to 2.1	2.82
Medium density	2	from 55 to 329	Less than 1320 sqm	from 2.2 to 13.19	2.91
High density	3	from 330 to 2500	Until 10,000 sqm	from 13.20 to 100	0.65

Density values must always be related to the context being analyzed. If we compare these values with the ones obtained in Mustafa, Van Rompaey, et al., 2018 we notice that there is a strong disparity: the first three density classes of this work are positioned between the intervals corresponding to the first two classes of Mustafà's work [212]. This is highlighted by the lower limit of the high-density class which corresponds to an area of 1320 sq.m of buildings per hectare and a coverage ratio of only 13%, in the reference area of 1 ha. The percentage of cell in high density class over the entire study area is 0.65% and, comparing them with the urban aggregates of Saganeiti et al., 2018, we observe that they correspond to the largest urban aggregates of each municipality in the region, i.e. compact urban centers, for a percentage equal to 66%.

Table 9 show the amount of change that occurred in the study area between the various density classes and for the two temporal periods: 1989-1998 and 1998-2013. Dominant over all changes, for both time phases, is the expansion of the low-density class (greater than 40%). The low-density class has coverage percentages corresponding to those of sprinkling which, therefore, can be considered the dominant transformation in the study area.

Table 9 Cells changed from one class to another and percentage of change for each class based on total transformation.

1989 → 1998	Class 0	Class 1	Class 2	Class 3
Class 0	-	5895 (42.76%)	3725 (27.02%)	532 (3.86%)
Class 1	-	-	2850 (20.67%)	54 (0.39%)
Class 2	-	-	-	731 (5.30%)

1998 → 2013	Class 0	Class 1	Class 2	Class 3
Class 0	-	5353 (40.49%)	3451 (26.11%)	630 (4.76%)
Class 1	-	-	2831 (21.41%)	75 (0.57%)
Class 2	-	-	-	880 (6.66%)

5.1.2. Built-up causative factors

The drivers considered to have an impact on the settlement system are listed in the Table 10, they will be used to model the transition rules, with the MLR. The drivers were chosen following the literature review and the principal characteristics of the study area. The expected results of the MLR are, for example, a negative correlation between the proximity driver from cities and urban transformation since the general trend is to build new urban agglomerations close to existing ones in order to minimize/contain the costs of infrastructures and public services [201,206,213,214]. A negative correlation with the drivers of proximity from roads is also expected, because the probability of expansion in the vicinity of existing roads is generally higher [215–217].

Drivers related to social and economic factors are continuous data distributed by municipality and available from the National Institute of Statistics -ISTAT - [132]. The other drivers are derived from data available on the regional geo portal (RSDI [170]). In particular, the slope was obtained from the elevation raster. Proximity factors from roads and railway stations were derived from a vector dataset and were calculated using the Euclidean distance method. Roads were classified into three categories: highways, suburban roads, and local roads. Proximity factors also included distances to large cities (X7) and medium-sized cities (X8). Considering the characteristics of the study area, large cities are those with a population > 50,000 inhabitants, i.e. the two provincial capitals (Potenza and Matera); medium-sized cities are those with a population between 10,000 and 50,000 inhabitants, cities that cover an important role at regional level from the point of view of economy, industry, agriculture or tourism. For the urban policy factors, all strict constraints on possible urbanization existing in the territory were considered, such as mountains above 1200m, buffers for rivers, lakes and coastal territories, archaeological heritage, forests, road and rail buffers and hydrogeological risk (0: not urbanizable area, 1: urbanizable area). All drivers were rasterized with a 100x100 pixel resolution and standardized, except the zoning driver which is a binary map.

Table 10 Built-up causative factors.

Driver	Name	Datum	Unit	Predictive variables
X_1	Elevation	continuous	meter	Physical factors
X_2	Slope	continuous	percent	
X_3	Distance to railway station	continuous	meter	Proximity factors
X_4	Distance to road 01 highways	continuous	meter	
X_5	Distance to road 02 suburban roads	continuous	meter	
X_6	Distance to road 03 local roads	continuous	meter	
X_7	Distance to large city	continuous	meter	
X_8	Distance to medium city	continuous	meter	
X_9	Population density	continuous	percent	Social factors
X_{10}	Employment rate	continuous	percent	Economic factors
X_{11}	Zoning	categorical	Binary (0-1)	Urban policies

5.2. Methodology

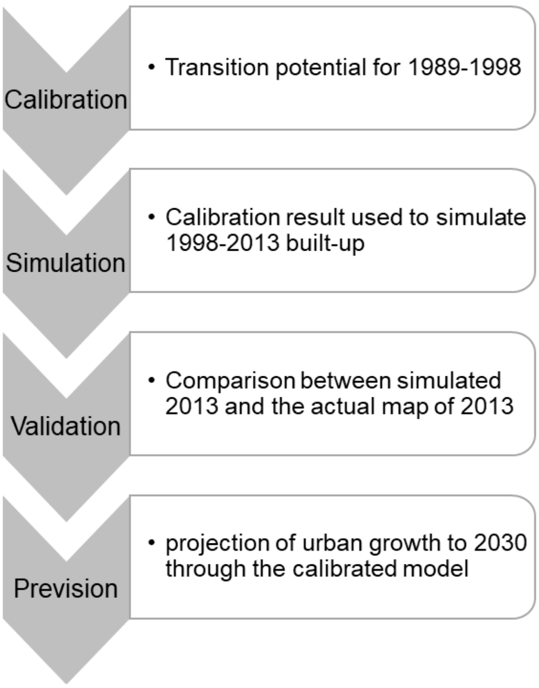


Fig. 45 A simple outline of the methodology

Fig. 45 shows a simplified diagram of the methodology applied in this research to project urban sprinkling to the year 2030. Built-up density maps were used for the calibration phase (1989-1998) and validation phase (1998-2013). Two components were considered for the calculation of the transition potential from one density class to another for the calibration phase. The first component concerns the built-up development causative factors, calibrated with the MLR. The second component was the CA neighborhood effects that were calibrated using a MOGA as in Mustafa et al. [211]. The calibrated parameters were used to simulate built-up pattern of 2013. We then validated our model by comparing the simulated 2013 with the actual 2013.

5.2.1. Transition potential and calibration process

The general goal of the calibration process is to obtain the best set of parameters that are well adapted to the urban expansion of a specific area. The estimation of the transition potential *(P)* of a cell *(ij)* changing its state from no-built up to one of the other density classes (or from one density class to another) is done as follows Mustafa et al. [211]:

Eq e

$$P_{ij} = \sqrt{(P_c)_{ij} \text{x} (P_n)_{ij}}$$

where $(P_c)_{ij}$ represents the transition probability based on the drivers affecting the expansion process (see Table 10), and $(P_n)_{ij}$ represent the neighborhood effect on the cells *ij* for each density classes. The $(P_c)_{ij}$ will be determined using MLR. MLR, is an extension of the binary logistic regression, it returns more than two response categories that are considered simultaneously to describe the relationship between one or more independent variables [218]. In this study MLR was performed for class 0, class 1 and class 2; the dependent variables (*Y*) are represented, respectively for the classes analyzed, the change from class 0 to classes 1, 2 and 3, the change from class 1 to class 2 and the change from class 2 to 3. Considering the general form of MLR the probability of change for each *k* class is obtained by the Eq f.

Eq f

$$((P_c)_{ij}, Y = k_0) = \frac{1}{1 + \exp\left(\alpha_{k_1} + \beta_{k_1 1} X_1 + \cdots + \beta_{k_1 v} X_v\right) + \cdots + \exp\left(\alpha_{k_n} + \beta_{k_n 1} X_1 + \cdots + \beta_{k_n v} X_v\right)}$$

…

$$((P_c)_{ij}, Y = k_n) = \frac{\exp\left(\alpha_{k_n} + \beta_{k_n 1} X_1 + \cdots + \beta_{k_n v} X_v\right)}{1 + \exp\left(\alpha_{k_1} + \beta_{k_1 1} X_1 + \cdots + \beta_{k_1 v} X_v\right) + \cdots + \exp\left(\alpha_{k_n} + \beta_{k_n 1} X_1 + \cdots + \beta_{k_n v} X_v\right)}$$

Where: $(P_c)_{ij}$ represents the probability that in a cell *ij*, the dependent variable *Y* changes from the reference class to the specific class k_n; ($X_1 \dots . X_v$) constitutes the set of independent variables; β is the regression coefficient for each independent variable; α is a coefficient representing the intercept between a specific class *kn* and the reference class. In order to obtain the best coefficients, MLR uses the maximum likelihood estimation method.

The MLR provides a set of coefficients β which expresses the relationship between the independent variables and the expansion and densification processes. Using these coefficients, we generated a probability map for each class according to Eq f. The goodness of the MLR fit is expressed by the relative operating characteristic (ROC) coefficient, according to which values of the coefficient between 0.5 (random fit) and 1 (perfect fit) [219,220]. A multicollinearity test, variance inflation factor (VIF), has been performed to verify that there are no driving forces measuring the same phenomenon among all the independent variables[221–223]. The presence of multicollinearity between the variables is expressed by VIF values greater than 4. Fig. 46 show all the predictive variables (standardized) for the temporal step 1989-1998 and used in the MLR.

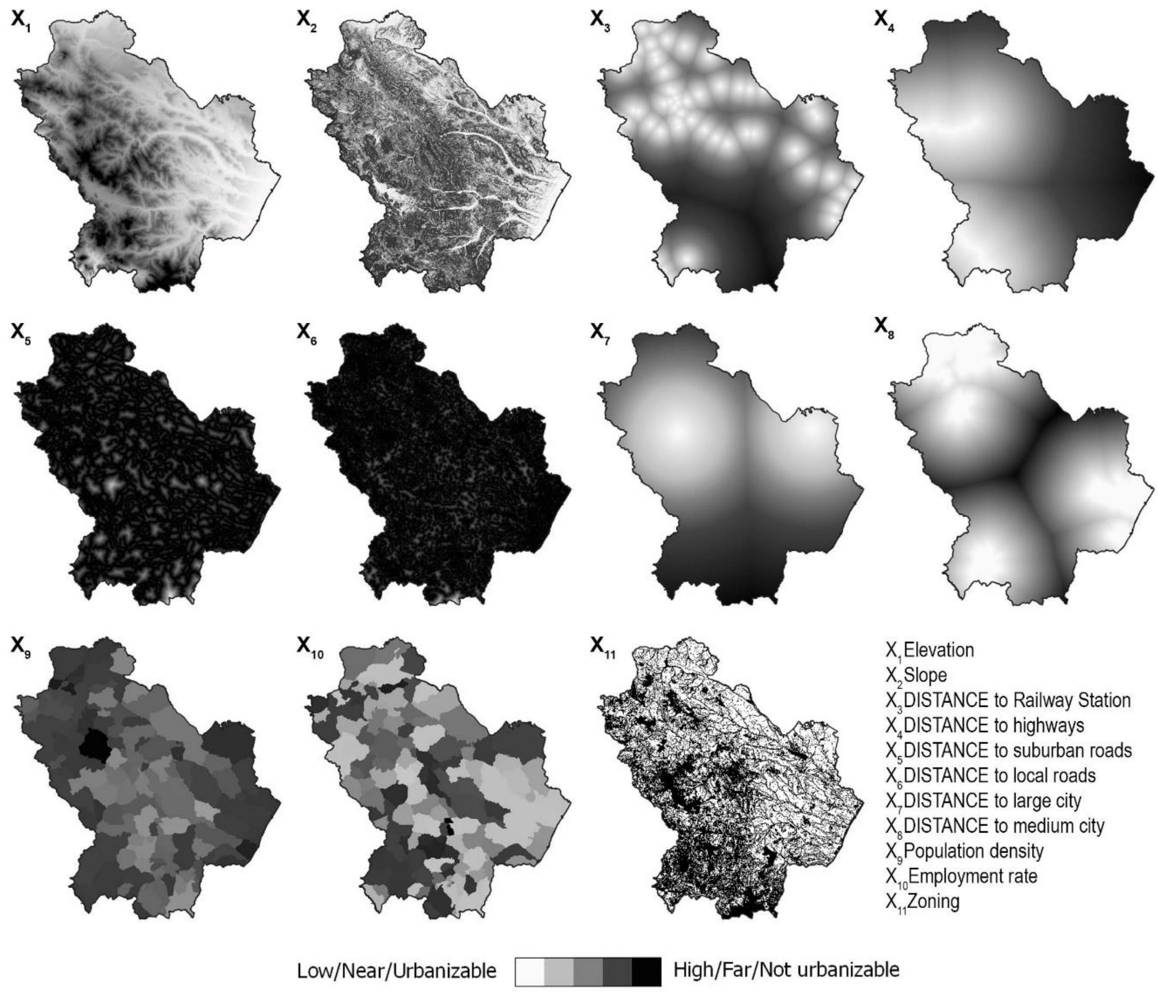


Fig. 46 Predictive variables maps.

The $(P_n)_{ij}$, the neighborhood effect, has been evaluated through a 3x3 moving window. It will be determined using the approach of cellular automata (CA), with the method proposed by [224] and already applied in [211], expressed with Eq g. Mustafa, Rienow, et al., (2018) [216], Chen et al., (2014) [225] and Poelmans & Van Rompaey, (2009) [210] examined several square sizes and found that the model runs with the 3x3 neighborhood moving window produced a land-use pattern that most fits the actual pattern. Furthermore, Mustafa, Rienow, et al., (2018) used a 100 m resolution, similar to that of this research, and found that a 3x3 neighborhood moving window outperformed other window sizes (5x5, 7x7, 9x9, and 11x11).

Eq g

$$(P_n)_{ij} = \sum_k \sum_x \sum_d W_{kxd} {*} I_{kxd}$$

Where: W_{kxd} is the weighting parameter assigned to a cell *ij* with class *k*, which represents one of the building density class, at position *x* at distance zone *d*; I_{kxd} is 1 if a cell in distance zone d is occupied by class *k* or 0 otherwise. Eq g parameters are calibrated with multi-objective genetic algorithm (MOGA) for expansion and a genetic algorithm (GA) for densification. The output of the optimization process consists of a set of solutions defined Pareto front [226]. It is a set of optimal solutions consisting of all the points that are not dominated. The optimal pareto font solution is realized when the allocation of resources is such that it is impossible to make improvements to the system [227].

For both MOGA and GA the parameters used to set the optimization process are described below. At the initialization process, the algorithm creates a random population of 200 individuals. Each new generation is initiated by selecting parents from the former generation. The algorithm randomly picks 2 individuals, and then select the best individual according to its fitness score. A new individual is then generated by crossing over a couple of parents according to a binary tournament at 0.8. The Gaussian function was chosen to mutate every new individual by adding a random number to each vector entry of an individual. This random number is taken from a Gaussian distribution centered on zero. The standard deviation of this distribution is controlled with two parameters: the scale parameter (2.00) and he shrink parameter (1.00). The number of generations is flexible. However, we set a convergence stopping criterion when the fitness score for successive 25 generations is less than 0.001. The parameters values that maximize the objective function will be selected as the best calibration outcome. The objective function for the calibration is a fuzzy membership function.

5.2.2. Model performance and fitness function

The model's ability to predict the transition from one density class to another is verified (tested) by comparing the 2013 map obtained with the calibration process (simulated map) with the 2013 actual map. The comparison considers only the new built up transition from 1998 to 2013 and it is calculated with a fuzziness similarity index calculated as follows (Eq h) [211].

Eq h

$$A_k = \frac{\sum_{x_k \in X_{k,sim}} \left| I_{x_{k0}} (1/2)^{0/2}, I_{x_{k1}} (1/2)^{1/2}, \ldots, I_{x_{kd}} (1/2)^{d/2} \right|_{max}}{X_{k,actual}} * 100$$

A_k is the average fuzziness index (between 0 and 100) for each class *k*; I_{x_k} is 1 if cell i_k in the simulated map at zone *d* (between 0 and 4) has similar building density class to one cell at zone *d* in the actual map or else 0. $X_{k,sim}$ corresponds to the number of class *k* changes in the simulated map and $X_{k,actual}$ in the actual map.

5.3. Urban sprinkling projection in the year 2030

In this section the results of MLR, calibration and validation process are listed and discussed. The VIF index used for the multicollinearity test among the independent variables, with values < 2.58 implying no collinearities, so that all the 11 variables presented in the Table 10 were introduced in MLR. The X_9 and X_{10} variables refer to population density and employment rate respectively for the year 2001. This data is collected at municipal level and, in particular, the employment rate was calculated by dividing the employed population by the resident population in each municipality.

Fig. 47 shows the MLR coefficients with the respective level of significance for each transition analyzed (expansion and densification process) for the period 1989-1998. Since the amount of change was marginal, the densification process from class 1 to 3 has not been considered.

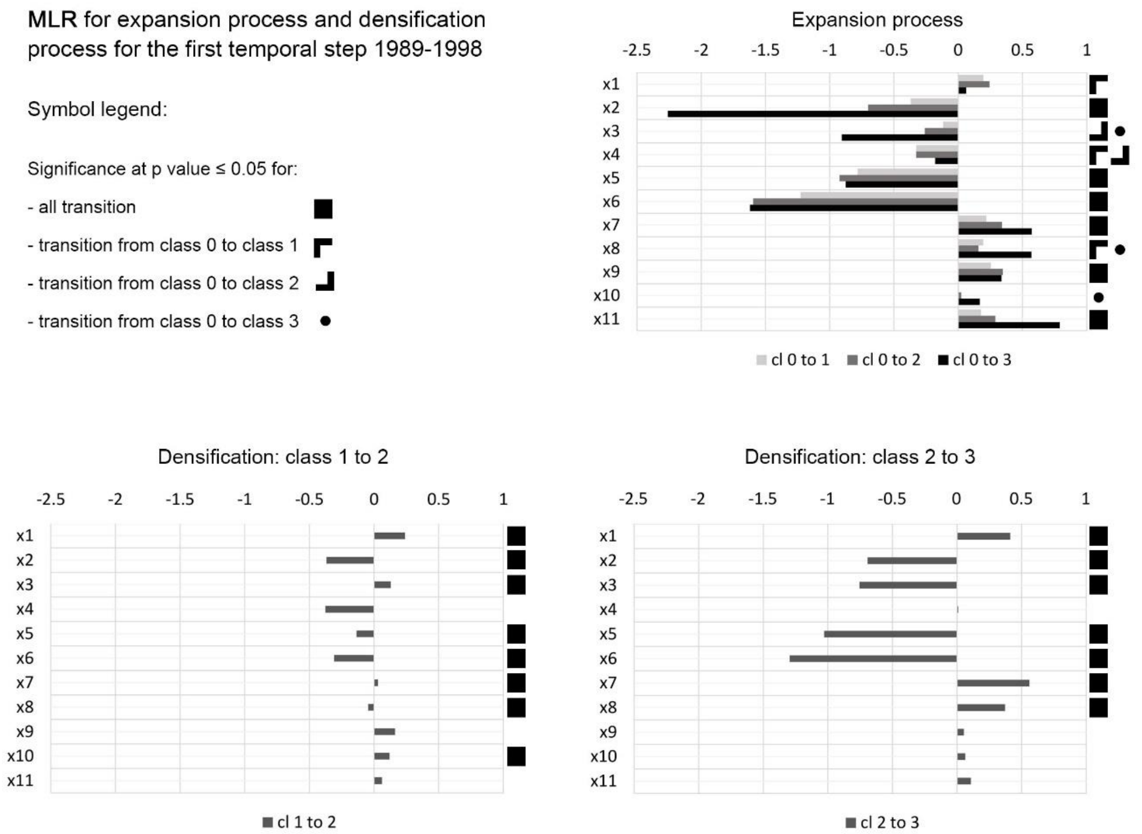


Fig. 47 MLR coefficients for the expansion and densification process at first temporal step 1989-1998.

For the expansion process, the most influential factor is the distance to local roads for transition to density class 0 to class 1 and 2 and, the slope for the transition from class 0 to class 3. The most important factors for the densification process, are the slope for densification to class 1 to class 2 and proximity to local road for transition from class 2 to class 3. As regards the correlation between the dependent variable and the predictive variables, the correlation with the proximity factors from roads and stations was negative for the expansion processes. Therefore, as apected in the section 5.1.2, the probability of cells changing their state from non-urban to urban, increases by decreasing distance to roads and railway stations. This behaviour, i.e. more urban transformation in the proximity of train stations and major roads, is usually considered as key component of a sustainable settlement system. Only for the transition from class 1 to class 2 of the densification process, the correlation with the proximity of medium-sized cities was negative. Interestingly, for all other transitions the correlation between urban transformations and proximity variables from cities was positive. Therefore, instead of building new urban agglomerations close to the existing ones to minimize/contain the costs of infrastructure and public services in the present case study the trend is to build further away from existing cities, away from roads and train stations, in an ever increasing scattered pattern that dramatically increases social costs. This is precisely what we defined as urban sprinkling, by contrast with urban sprawl that rather tends to develop and consolidate along existing urban cores even though with lower densities than central areas.

The correlation with the variables X_9 and X_{10}, which represent socioeconomic factors, is positive but poorly correlated for almost all transitions. This is in contrast to other research which has shown that, in both high [228,229] and low settlement density contexts [230], the drivers that most influence urban expansion are those related to population density and employment rate.

The correlation between the urban transformation processes and the physical factor of elevation is positive. This is due to the high altimetry in which most of the municipalities of Basilicata region reside, as evidenced in the research [231], rural buildings (abandoned or not) in the Basilicata region are found at an average altitude of 500 meters above sea level.

The ROC values of MLR for the expansion process ROC values are: 0.89 for transition from class 0 to class 1 and 2, and 0.85 for transition from class 0 to class 3; for the densification process, ROC values are 0.67 for densification from class 1 to class 2 and 0.73 for densification from class 2 to 3.

The optimization for expansion process, stopped at generation 122 and returned a set of Pareto front solutions among which the best solution has been selected. The calibrated map of 1989-1998 has been used for the validation of 1998-2013 map. The accuracy rates for the validation process are 55.80%, 34.14% and 23.75% for class 0 to 1, 0 to 2 and 0 to 3 respectively. The GA optimization for densification from 1 to 2 stopped at 58 generation and for densification from 2 to 3 at 61 generation with an accuracy rate for the validation process of 47.64% and 40.47% respectively. Fig. 48 shows the optimal weights obtained for all transformation processes that define the neighborhood interaction. The results show that the probability of expansion of the low-density class increases with the expansion of the existing urbanized cells (density class 1,2 and 3) in particularly class 1. The probability of expansion of class 2 is remarkably correlated with the presence of high-density cells. The expansion of class 3 is strongly correlated with the presence of high-density cells.

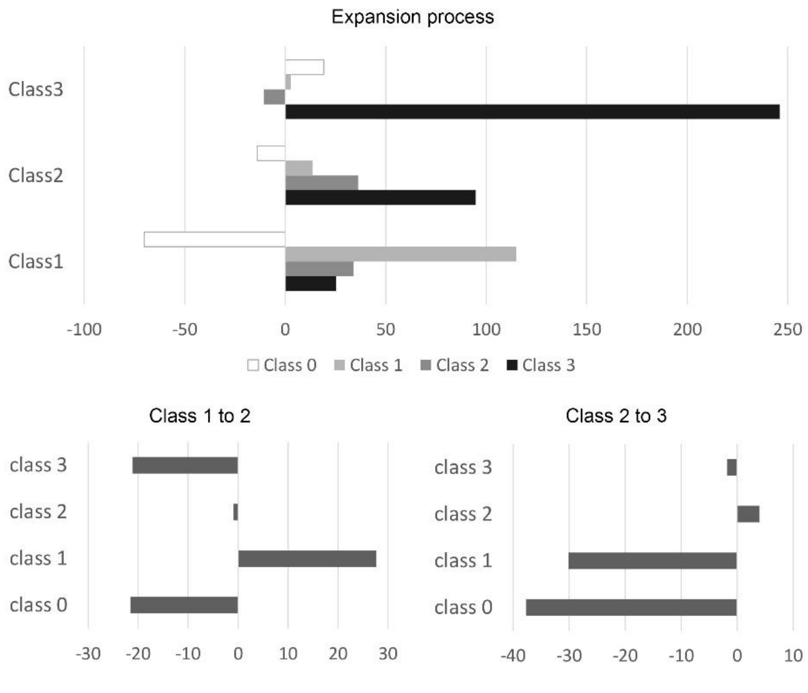


Fig. 48 Weighting values of neighborhood parameters values for all transformation processes.

The probability of transition from class 1 to 2 is positively linked with the existence of low-density cells and negatively with the others. The densification process from class 2 to 3 shows a strong negative relation with non-urbanized and low-density cells and positive link with medium density cells.These results show that the trend is to develop new buildings near low-density areas increasing fragmentation and fueling urban sprinkling. Furthermore, densification processes take place near low and medium density cells leading to the development of settlement that are located far from high density areas (medium and large cities), and that will require new services and infrastructures.

The results of the 2030 projections show a loss of 7649 hectares of non-urbanized land. This is almost half the administrative surface of the city of Potenza (17543 hectares [132]). In the study area, the estimated loss of area from 2013 to 2030 corresponds to 450 hectares per year. This area is scattered over the territory since major changes concern the low-density class - corresponding to urban sprinkling – whose variation that amounts to 73% of the total change. Low-density cells increased by 17% compared to 2013. In the 2030 prediction, the medium density class is affected by a percentage of change of 22% of the total variation, while the remaining part (5%) concerns class 3. Fig. 49 shows some of the most significant places in the study area through a comparison between the actual 2013 maps and those of 2030 as predicted by the model.

A disaggregation of the data on the basis of the two provincial territories (province of Potenza and province of Matera) shows that the province of Potenza undergoes a greater change in terms of absolute values equal to 83% of the total change. The biggest changes concern: (i) the city of Potenza, which in 2030 increased its low-density area by 925 hectares and three near municipalities: Tito, Picerno and Pignola, with an increase by each municipality, respectively, of 180, 207 and 139 hectares of low-density area (see Fig. 49 c); (ii) the municipality of Melfi, located in the extreme north-west of the province of Potenza (see Fig. 49 d), affected by a substantial increase (compared to other municipalities) of the medium density areas of 185 hectares (75% of the total changes in the municipality).

For the territory of the province of Matera the total change in 2030 is equal to 17% of the total regional variation. Most change is located along the coast and mainly concerns density classes 2 and 3. With reference to Fig. 49 a, the major changes from 2013 to 2030 are recorded in the municipality of Policoro and concern the medium density class for an area of 164 hectares. The municipality of Scanzano Jonico, registers an increase in the medium density area of 59 hectares (54% of the total) and an increase in the high-density area of 45 hectares; only 5% of the total change affects the low-density class. In the municipality of Pisticci, instead, the transformations concern in the same quantity the density class 1 and class 3 for a total of 54 hectares. As regards the city of Matera (Fig. 49 b), the provincial capital, the biggest changes concern the low-density classes (211 hectares) and medium density classes (200 hectares), with a total change since 2013 of 1.19%.

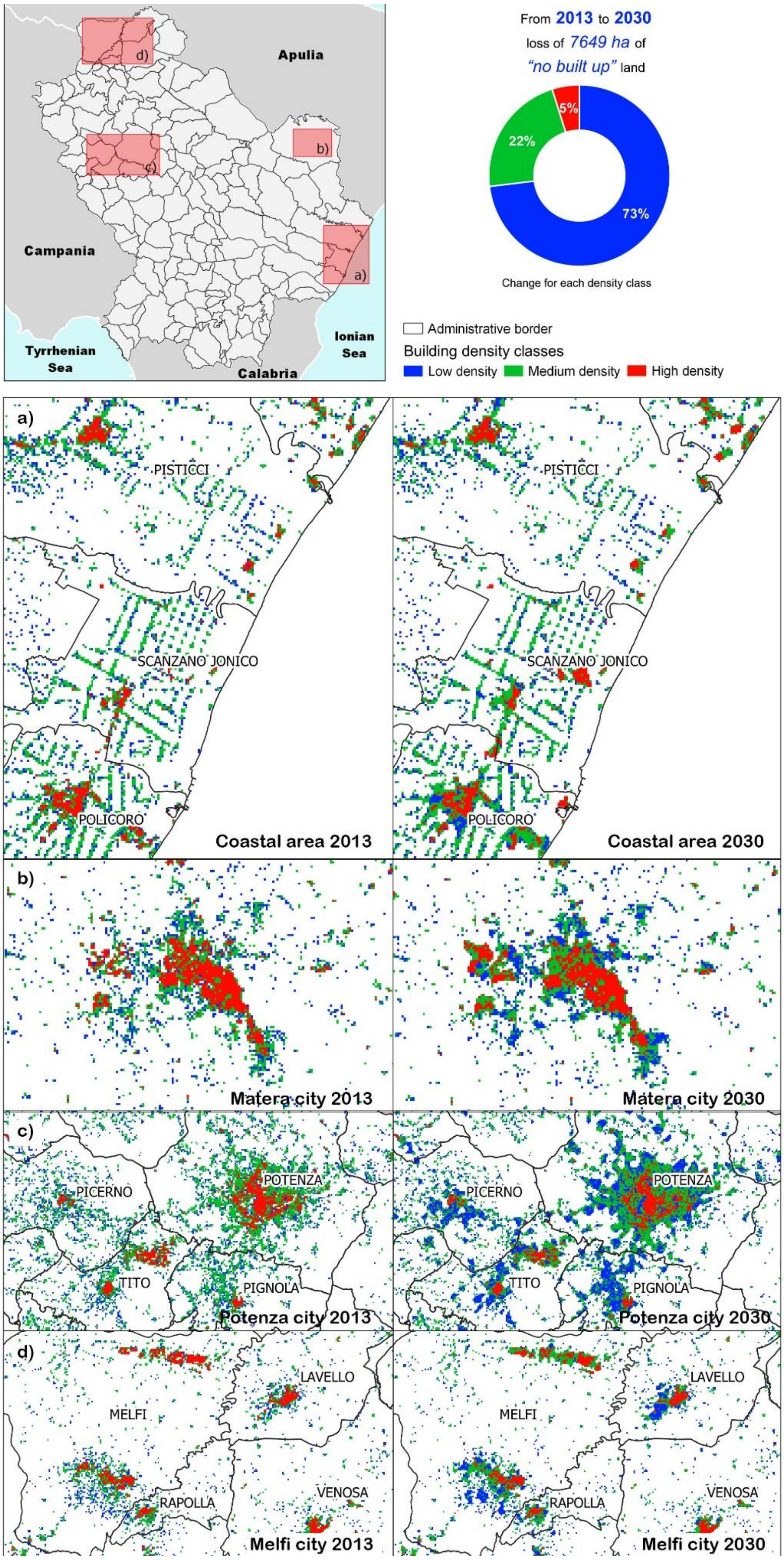


Fig. 49 Some examples of the study area. On the left the maps of 2013 actual and on the right those of 2030 predicted

5.4. Discussion and main conclusions

The model applied in this chapter addresses the dynamics of urban expansion through a multi-density approach. It was possible to assess the different relationship between built-up causative factors and built-up density classes for each transition, with specific factors derived from MLR and CA coefficients for each density class.

Specifically, it allows to read and analyze the different impacts of drivers on the transformation modalities, especially on the expansion and densification processes.

One of the limitations of this study is that built-up density does not consider building heights and uses. This could lead to misreading of the expansion process. An example concerns the predicted expansion along the coast area (Fig. 49 a) which has certainly undergone an increase in expansion due to the development of the tourism sector. In fact, the tourism sector, even if it is not the dominant development sector in the Basilicata region, has greatly influenced the expansion of the Ionian coast with the development of numerous tourist resorts and apartments for vacations (especially in the municipalities of Policoro and Pisticci [157] - Fig. 49 a). However, in the municipality of Scanzano Jonico there was a strong expansion of the high-density class in 2030, resulting from the expansion over the years of structures at the service of agriculture (greenhouses, barns and warehouses). In this case a distinction of uses of the buildings would have allowed to discriminate the buildings of purely industrial use going to improve the final result of the 2030 projection. The variable height of the buildings instead would have made it possible to make further considerations on the number of floors per building, on the population density within building complexes and therefore assess the final projection not only on the shape and size of the building but on its effective capacity. A possible future research in the construction of the model considering only residential buildings. In addition, the variables concerning population density and employment rate were used at municipal level (due to the unavailability of other data). Certainly, a more detailed data on the cadastral sections or on the working compartments would give inclusive results. Since the results of the 2030 projection mostly concern density class 1, i.e. the one corresponding to sprinkling, possible developments in this work could concern the application of the model to predict the variation in the sprinkling index.

An innovative aspect of this study consists in considering urban expansion not in a dual way (built-up/no built-up) but along four density classes (no built-up, low, medium and high density). This multi-density approach allowed to evaluate, through the MLR, the different correlations of each density class with the built-up causative factors considered. Both expansion and densification processes were explored. From the results of the MLR a scarce significance of the socioeconomic variables on all the expansion processes have emerged. Observed urban expansion is inversely proportional to the demographic growth. This trend is typical at national scale not only in the regional context of Basilicata [82].

This phenomenon leads to new urban expansion in the absence of real estate demand and therefore to an unnecessary waste of land with all its consequences. The results of the MLR show that the most important factor influencing urban expansion is the proximity to roads. In particular, the correlation between the variable of proximity from local roads and urban expansion is the most significant for the expansion process (transition from class 0 to all other classes). This corresponds to the typical phenomenon of urban sprinkling in which new settlements tend to be built close to local roads (with less availability of services) and far from the main public service centers with an increasing of social costs [22,33]. The results of the CA neighborhood effects show that the general trend is to realize new buildings (in the low-density class) in the vicinity of low-density areas, which further increases the sprinkling effect. In addition, densification processes take place close to low and medium density areas. In a sustainable urban development, it is appropriate to encourage densification processes close to medium and high-density cells where more services are concentrated, thus limiting further dispersion of urbanized cells on the territory.

6. Conclusions

Principal results

From the development of the ontology and the construction of the thesaurus has emerged that *land consumption* assumes a different meaning than the concept of *land take* because while the first refers to the transformation processes of land cover adding, the intensive use of soils, in addition to urban expansion, the second refers only to completely artificial surfaces (sealed).

Land take is generally irreversible, however, in the medium-long term it could be reversible; land consumption, on the other hand, based on the intensity of its transformation, could be reversible in the medium-long term [40]. Often the two concepts are used in an interchangeable way so as not to make comparable results and provide inaccurate information. As with these two concepts, semantic conflict exists for numerous other concepts related to land use planning and all the dynamics related to land consumption. It is irrational to legislate (at national, regional and local scale) on urban policies to limit and contain land consumption without the construction of a hierarchy of concepts or better still a shared and approved ontology.

It is essential to speak the same language. In Italy, the existent definitions to describe the land take phenomenon at national and regional level are still numerous and not always univocally defined. Often the different meanings refer to sectoral regulatory frameworks that propose definitions of soil consumption calibrated to the territorial context but also motivated by economic and social evaluations. At the European level, there are many agencies that over the years have dealt with soil and specifically to monitor the phenomena of land consumption (for example by Eurostat, Environment European Agency - EEA, Joint Research Center – JRC [40,108,110]) so it is appropriate that the Italian nation always refers to what has already been stated at European level and what are the indicators currently considered.

It is urgent to address the issue of land take according to different indicators that allow to evaluate it not only in quantitative terms but also on the basis of the shape of urban settlements and their dispersion on the territory. The main effort must be directed to the introduction of a planning system that orients future territorial transformations towards a sustainable perspective.

From Chapter 3 emerges a dispersed spatial configuration of urban settlements in Italy. The urban expansion in most Italian provinces (63%) in the 2019 has followed the of urban sprinkling dynamics, while in the 37% of provinces the dynamics of urban sprawl prevails. Both represent transformation processes characterized by settlement dispersion and that generate low-density urban settlements and therefore unsustainable from an environmental, social and economic point of view. In line with an old

and now weak urban planning [24,60] to deal with the new issues concerning land management, all the regions of southern Italy are characterized by a very high urban dispersion. The Basilicata region has the highest degree of urban dispersion coupled with a low percentage of urbanized area in 2019.
From the analysis of the dimensions of fragmentation in Chapter 4, a territory that fragmented by several components of the settlement system, both traditional and more recent, emerges. Relationships were found between urban expansion and road infrastructure development and the recent installation of renewable energy facilities with the different fragmentation indices used. The sprinkling calculated with all components of the settlement system returns a picture of the transformation dynamics occurred in the regional territory (fragmentation and compaction); between 50s' and 2018 the median value of the sprinkling index increases by 54%. This translates into an increase in total fragmentation caused by anthropic settlements. Concerning the Build layer from the 50s to 2018 fragmented areas increased at the expense of those classified as "No urban area". The greatest change occurred between the 50s and 1989 when highly fragmented areas increased by 50%. In subsequent years, from 2008 onward, fragmentation caused by buildings has markedly decreased but has been replaced by fragmentation generated by the uncontrolled installation of numerous wind turbines. The gradual decrease in land transformation due to the Build layer leads to a turn-over in the principal causes of land take. In 2018, the sealed area for the installation of new wind turbines (RES_w layer), results in more than twice the sealed area due to the construction of new buildings (12 sq km). The assessment of the infrastructure fragmentation index on the basis of the same grid used for the SPX index allowed to compare the different results. It emerges that compaction produces fewer costs associated with the construction of new road infrastructure since cells containing only one urban aggregate (in SPX_Build_1) are not fragmented in IFI_1. This means that the same cells do not contain roads because the urban aggregate is evidently served by infrastructures that are located in the adjacent cell already urbanized. In turn, the IFI_m points out that between 2013 and 2018, the fragmentation degree increased in the municipalities where the largest number of wind turbines were installed.
From the analysis of landscape metrics and diversity indices it emerges that landscape fragmentation in the Basilicata region is constantly increasing, despite the fact that it is one of the Italian regions with the lowest percentage of consumed soil [57]. From 1990 to 2000 there has been a gradual increase in fragmentation due mainly to the development of buildings and roads to serve these new expansion areas. From 2000 to 2012, fragmentation continues to increase mainly due to increased intensive agricultural production, which has taken land away from forests and grasslands particularly. From 2012 to 2018 the landscape fragmentation degree continues to increase mainly due to the strong expansion of RES facilities, which have grown exponentially in the region in recent years, and the infrastructure network created to reach these facilities.
The simulation of the 2030 scenario was used to model the plausible spatial consequences of future urban expansion considering specific planning regulations, to calculate the potential impact of land transformation, and to create effective strategies for possible future transformation [232]. It emerges that the greatest change in the year 2030 occurs in the class corresponding to sprinkling (density class 1) and mainly the territory of the province of Potenza. In the territory of the province of Matera, most changes are concentrated along the coast and does not primarily concern sprinkling but, on the contrary,

density classes 2 and 3. For this reason, and for other factors linked to the different physical characteristics of the two provincial territories, in terms of altitude, road infrastructure, number of railway stations and territorial extension, it would be appropriate to carry out the analysis on the two territories considering different built-up causative factors. By distributing the total area lost - i.e. the area that has changed from "not built-up" to the other classes of density - for the total regional population in 2019 (562,869 inhabitants [132]), we obtain a loss of about 136 square meters per capita in 2030. This area is subtracted from its natural use at the expense of non-existent demographic demand.

Considerations and main remarks on urban sprinkling as a new perspective of land take

The need to investigate and deepen the urban transformation dynamics occurred in Italy and in the Basilicata region since the 50s emerges in response to the implementation of several policies at European level to contain/limit land take (*No net land take by 2050* [27,30,50,51]). What can be done about the target of zero net land take by 2050 (EU Environmental Action Programme to 2020 (7th EAP))? Limiting soil sealing and stopping soil consumption means blocking the conversion of natural or semi-natural land into artificial ones. National and regional policies have the task of limiting, or better stopping, the phenomena of uncontrolled urban expansion, such as urban sprawl and urban sprinkling, phenomena that cause a fragmentation of the urban and rural landscape and are less sustainable than the simple expansion within the existing city as the densification processes. In order to stop net soil consumption, it is necessary to encourage the reuse of already built-up areas, such as brownfield sites, as part of urban regeneration strategies whose aim is to limit soil sealing. Mitigation measures must be adopted to intervene on excessively impermeable areas in order to maintain the basic functions of the soil and reduce the negative effects (direct or indirect) that impact the environment and human well-being in general. For example, if road infrastructures are considered, mitigation measures may include replacing asphalt with permeable materials; for water management systems, green infrastructure or other nature-based solutions may be used.

The landscape fragmentation and the insularity of ecosystems constitute a central moment for the achievement of sustainability standards in the procedures of territorial government. It is essential that the effects of ecosystem disruption take on a "measurable" character, entering the list of indicators of urban and territorial quality that European guidelines to national communities currently consider essential and decisive to measure the efficiency of the management of land transformation. Specifically, the urban fragmentation measured with the SPX, IFI and, diversity index and landscape metrics represents good indicators to monitor land take not only from a numerical point of view (changes' speed and percentage increases) but also from the point of view of size and shape. The temporal analysis of the indicators also allows policy makers to have a clear picture of what has happened previously and to be able to implement policies in favor of flattening (rather than increasing) the growth curve of landscape fragmentation. These policies would directly affect the European Commission's "zero net land take by 2050" goals and decrease in land degradation.

Grid-based assessment of the sprinkling index could be an excellent tool for policy makers in decisions on land transformation. Policies aimed at limiting land take should be aimed at preserving first of all those cells classified as "No urban"; where it is unavoidable to transform the land and then build new settlements it is necessary to implement policies aimed at preferring cells with a low sprinkling index, i.e. those tending to compaction.

The environmental effects of sprinkling (similarly to that of the urban sprawl) are consequential to the conversion of agricultural land into built-up or simply sealed areas that are no longer available for food production, and this has altered the landscape and led to dramatic degradation of water quality and air quality, loss of the ecological soil functions, reduced ecosystem resilience, and high energy consumption [1,148,233]. The social costs of sprinkling are related to longer commuting times, dependence on motor vehicles, traffic congestion, and spatial separation of social classes [1,2,9,234].

A new housing development away from the main urban center requires new services that, in turn, require new road infrastructure and additional costs to the population. What drives users to build new homes in the rural landscape, isolated from existing housing developments? Certainly, a trigger is the infrastructure-related tax benefits for new homeowners, lower farmland costs, and the need for a new residence (sometimes a second residence) away from the chaos of the city.

As demonstrated by Manganelli et al.,[22] sprinkling produces social costs that are proportional to the degree of fragmentation. It has been shown that an increase of one degree of fragmentation produces a cost for the construction of new linear infrastructure of € 0.89 per cubic meter of total built volume (new and existing).

Due to the increase in future uncertainty caused by rapid environmental, societal, and technological change, exploring multiple scenarios has become increasingly important in urban planning. Land change modeling enables planners to have the ability to mold uncertain future land changes into more determined conditions via scenarios. Scenario planning identifies and evaluates various future expansion options, and helps stakeholders (e.g., agencies, local officials, developers, land owners, general public) to make better decisions for possible future conditions by comparing and assessing different and plausible growth options.

Assuming that in the context of Basilicata region the main transformation dynamics corresponds to urban sprinkling and the demographic trend is constantly decreasing - completely eliminating the real demand for real estate market - we ask the following question: why build a prediction model? Certainly, a prediction model in this context, could be a valid instrument of decision-making support system to identify, on the basis of prediction: (i) the most vulnerable areas to transformation, and where to develop ad hoc regulations to limit transformation or to transfer development in the proximity of areas suitable for transformation (those with a greater presence of public services); (ii) the areas susceptible and threatened by anthropic transformations where to implement measures for the protection and conservation of biodiversity and the naturalness of lands.

Simulating future urban expansion scenarios is fundamental to understand the spatial model in action in a given territory. It can help policy makers to adopt urban policies aimed at containing expansion. The aim of this work has been to project future business-as-usual scenario in urban sprinkling contexts in order to control and regulate urban transformation processes.

Appendix

A - Methodological annexes

A.1 Sprawl index

The urban sprawl index (I_S) has been used by the Organization for Economic Cooperation and Development (OECD) [160] to measure the growth of built-up areas in conjunction with population growth in metropolitan areas. In this research, it has been used at the regional level to have a generic measure of urban sprawl variability in conjunction with demographic trends from the 50's to the year 2018. The index is expressed by the following formula:

Eq i

$$I_S = \frac{urb_{i,t+n} - (urb_{i,t}\left(\frac{pop_{i,t+n}}{pop_{i,t}}\right))}{urb_{i,t}}$$

Where: *urb* refers to urban surface of study area (*i*), *t* refers to the year in which the investigation began, *t+n* refers to subsequent years and *pop* to population.
In cases of stable population, I_S expresses the expansion of urban areas. In contrast, when the population varies, the index expresses the increase or decrease in built-up area compared with an increase or decrease in population. Specifically there are three basic conditions: (*i*) I_S equal to 0 expresses a condition of stability, i.e. both the population and the urban area have remained stable over time or show positive variations between them proportional and congruent; (*ii*) I_S is negative if the demographic variation is more than proportional to the urban surface variation; (*iii*) I_S is positive when the urban surface variation is proportionally greater than the demographic variation that remains stable or decreases. For sumarize, the index is greater than zero when the expansion of the built-up area is greater than population growth, i.e. the population density of the area decreases.
The sprawl index for the Basilicata region was calculated, in Chapter 4, over the time interval 1950-2018 and using the urbanized surface (in square km) and population data used in chapter 3 at regional and provincial level.

A.2 Population density and building density

For each municipality in the region two indices were calculated: the population density D_p (Eq j) and the total amount of residential buildings per hectare D_b, (Eq k).The indices were calculated for the six time phases, while their variation was calculated between 1950 and 2013 since the latter represents the official data for the settlement system evolution, similarly, 2011 for the demography is the data of the last population ISTAT's census at the municipal level.

Eq j

$$D_p = \frac{Inhabitant}{Area}\left[\frac{number}{Ha}\right]$$

Eq k

$$D_b = \frac{Build\_r}{Area} \left[\frac{number}{Ha}\right]$$

Build_r is the sub layer of Build and represent the buildings for residential use.

A.3 Wind turbines buffer radius

For the assessment of the land occupation relative to the RES_w level, the influence buffers around wind farms were considered. These allow to evaluate not only the area occupied by the building or RES_w, which is inevitably compromised, but also the immediately surrounding areas [129,235]. A method based on the assumption that the cumulative land take is proportional to the energy production of wind turbines has been used. The hypothesis was verified by a sample of sixty wind turbines (twenty for each class). For each of them the perimeter of the footprint area was digitized and correlated to the power produced. The graph in the Figure a shows a positive correlation, with R^2 of 0.81, between the area occupied by the sampled wind turbines and their power output. The three clusters were then identified according to the class of wind turbines.

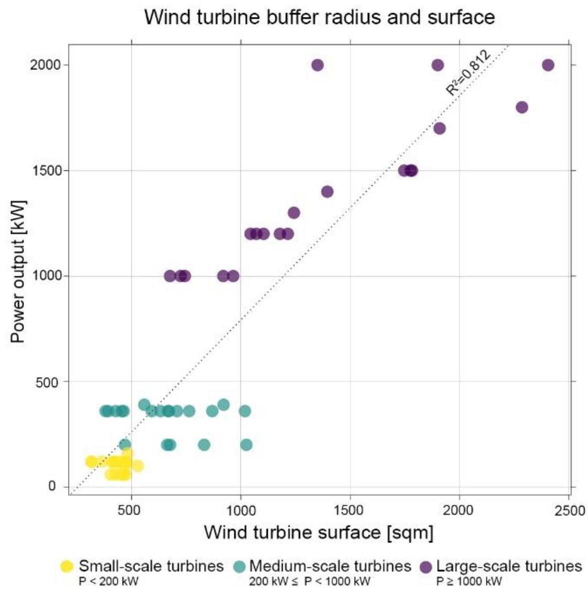


Figure a Correlation between the wind turbine surface and the power output

On the basis of these samples, in order to evaluate the land take related to the installation of wind turbines across the regional territory, it was assumed that the area occupied by each turbine is equal to the surface of a circle with buffer radius proportional to the power output class.

The buffer radius was calculated for each wind turbines class with the Eq l.

Eq l

$$Buffer\ radius = \sqrt[2]{\frac{\sum_1^n taken\ up\ area}{n°\ turbines} * \frac{1}{\pi}}$$

Where, for each turbines class: $\sum_1^n taken\ up\ area$ is the sum of the digitized surfaces (in square meters) including the pitches and the access roads to the individual turbines; $n°\ turbines$ corresponds to the number of wind turbines sampled, i.e. 20.

B - Tables

Tab i Results of P_U and Moran's I at Provincial level.

Code REG	Code PRO	Provinces	PU		D_p		Moran's I Queen		AltMEAN
			50'	*2019*	*50'*	*2019*	*50'*	*2019*	
1	1	Turin	5.49%	6.93%	209.94	329.95	0.955	0.807	1023.32
	2	Vercelli	2.52%	3.49%	93.67	82.08	0.883	0.787	634.99
	3	Novara	4.15%	8.72%	204.83	275.44	0.904	0.776	239.71
	4	Cuneo	2.33%	3.87%	84.21	85.17	0.845	0.756	974.17
	5	Asti	3.62%	6.06%	147.76	142.03	0.849	0.706	234.55
	6	Alessandria	2.00%	4.91%	134.37	118.49	0.874	0.750	283.16
	96	Biella	6.45%	6.73%	205.01	195.34	0.874	0.733	680.93
	103	Verbano-Cusio-Ossola	1.98%	2.03%	65.72	70.09	0.844	0.719	1348.84
2	7	Aosta	0.71%	0.95%	28.92	38.60	0.904	0.578	2103.46
3	12	Varese	8.60%	14.26%	398.16	743.45	0.905	0.672	362.07
	13	Como	4.04%	8.55%	282.80	468.56	0.875	0.672	689.65
	14	Sondrio	0.50%	1.53%	48.08	56.73	0.840	0.633	1842.92
	15	Milan	12.52%	20.90%	1224.17	2061.96	0.945	0.736	129.49
	16	Bergamo	2.81%	7.96%	247.67	404.31	0.882	0.718	813.57
	17	Brescia	2.49%	6.50%	179.34	264.53	0.885	0.736	730.34
	18	Pavia	3.44%	4.92%	170.97	184.26	0.889	0.714	179.44
	19	Cremona	3.76%	7.03%	215.56	202.66	0.895	0.775	53.62
	20	Mantua	3.85%	6.81%	181.66	176.33	0.845	0.738	30.43
	97	Lecco	3.69%	8.24%	264.50	418.10	0.865	0.686	743.49
	98	Lodi	3.61%	7.89%	230.41	293.95	0.887	0.778	66.01
	108	Monza and Brianza	15.43%	29.62%	973.63	2153.98	0.909	0.667	211.66
4	21	South Tyrol	0.74%	1.26%	45.19	71.89	0.759	0.634	1745.77
	22	Trento	1.09%	1.97%	63.55	87.16	0.852	0.666	1402.52
5	23	Verona	3.96%	9.06%	208.71	299.55	0.812	0.729	240.54
	24	Vicenza	4.15%	8.49%	223.52	317.06	0.809	0.697	496.27
	25	Belluno	1.14%	1.52%	65.70	56.33	0.804	0.626	1316.19
	26	Treviso	5.22%	11.59%	247.47	358.53	0.801	0.682	154.57
	27	Venice	3.91%	10.66%	300.08	345.83	0.819	0.732	2.68
	28	Padua	5.96%	13.32%	333.62	437.60	0.786	0.684	20.85
	29	Rovigo	2.79%	5.26%	192.05	129.44	0.795	0.701	4.48
6	30	Udine	3.08%	4.42%	112.86	108.06	0.922	0.677	630.57
	31	Gorizia	7.43%	9.08%	287.91	300.53	0.944	0.686	41.69
	32	Trieste	18.00%	19.00%	1411.08	1114.09	0.969	0.625	214.81
	93	Pordenone	4.39%	5.92%	107.89	137.73	0.929	0.694	508.33
7	8	Imperia	1.55%	3.40%	144.86	185.51	0.897	0.595	631.36
	9	Savona	1.82%	3.83%	154.08	178.85	0.894	0.624	483.6
	10	Genoa	3.28%	4.62%	508.01	460.04	0.917	0.640	566.46
	11	La Spezia	2.48%	4.61%	265.72	250.10	0.904	0.650	389.23

8	33	Piacenza	1.51%	4.60%	112.60	111.13	0.930	0.716	402.16
	34	Parma	1.23%	4.59%	113.52	131.02	0.936	0.725	468.04
	35	Reggio nell'Emilia	1.58%	7.35%	170.31	232.19	0.932	0.721	366.39
	36	Modena	1.33%	7.00%	185.38	262.51	0.947	0.706	378.2
	37	Bologna	1.55%	5.11%	206.46	274.22	0.957	0.672	242.89
	38	Ferrara	1.66%	4.18%	160.37	131.82	0.946	0.694	4.34
	39	Ravenna	1.70%	5.44%	158.73	209.75	0.948	0.687	63.67
	40	Forlì-Cesena	1.17%	4.09%	136.51	166.20	0.949	0.688	372.53
	99	Rimini	2.92%	8.29%	222.95	393.71	0.941	0.688	277.13
9	45	Massa and Carrara	1.25%	3.94%	177.29	169.05	0.692	0.639	574.8
	46	Lucca	1.71%	5.76%	206.95	218.78	0.682	0.638	533.37
	47	Pistoia	1.49%	6.43%	228.00	303.68	0.625	0.663	514.95
	48	Florence	1.44%	4.50%	229.16	288.06	0.730	0.683	373.79
	49	Livorno	1.19%	6.31%	234.23	277.97	0.689	0.702	105.79
	50	Pisa	0.81%	4.34%	143.15	171.38	0.647	0.682	151.31
	51	Arezzo	0.69%	2.93%	102.16	106.18	0.624	0.632	527.56
	52	Siena	0.55%	2.03%	72.64	69.96	0.630	0.644	353.53
	53	Grosseto	0.32%	1.45%	47.23	49.28	0.642	0.611	237.04
	100	Prato	2.22%	10.40%	305.74	704.98	0.750	0.748	395.29
10	54	Perugia	1.85%	3.00%	91.97	103.85	0.811	0.653	526.11
	55	Terni	1.90%	2.48%	104.90	106.33	0.805	0.649	391.52
11	41	Pesaro and Urbino	2.68%	4.21%	119.30	140.30	0.794	0.663	366.74
	42	Ancona	2.88%	6.13%	203.93	240.75	0.742	0.687	240.91
	43	Macerata	1.53%	3.47%	108.58	113.34	0.677	0.643	521.32
	44	Ascoli Piceno	1.15%	3.97%	153.10	169.37	0.585	0.653	519.46
	109	Fermo	1.98%	5.28%	164.83	202.02	0.612	0.649	298.1
12	56	Viterbo	0.34%	2.80%	71.70	87.88	0.868	0.618	269.97
	57	Rieti	0.36%	1.52%	65.35	56.73	0.829	0.504	819.02
	58	Rome	2.13%	6.48%	401.83	811.31	0.919	0.564	269.01
	59	Latina	0.74%	7.13%	126.27	256.05	0.822	0.615	186.17
	60	Frosinone	0.62%	4.62%	144.86	151.19	0.800	0.606	529.4
13	66	L'Aquila	0.58%	1.71%	72.60	59.47	0.881	0.594	1138.13
	67	Teramo	0.66%	3.91%	139.81	158.28	0.767	0.636	556.9
	68	Pescara	0.71%	4.24%	195.64	260.17	0.674	0.610	458.75
	69	Chieti	0.86%	3.61%	154.72	149.06	0.800	0.612	466.13
14	70	Campobasso	0.56%	1.81%	99.60	76.09	0.766	0.576	460.9
	94	Isernia	0.45%	1.47%	76.85	55.30	0.808	0.583	786.05
15	61	Caserta	1.72%	7.20%	228.02	349.96	0.945	0.709	240.1
	62	Benevento	0.77%	4.60%	161.11	133.95	0.927	0.603	477.19
	63	Naples	16.19%	27.31%	1783.61	2643.88	0.952	0.671	153.9
	64	Avellino	1.31%	4.69%	177.13	150.07	0.915	0.592	611.68
	65	Salerno	1.86%	5.43%	170.18	223.40	0.931	0.623	487.63
16	71	Foggia	0.77%	2.07%	88.84	89.49	0.898	0.623	243.07
	72	Bari	1.42%	6.05%	242.98	327.68	0.934	0.633	301.82

	73	Taranto	0.94%	6.31%	173.77	236.73	0.907	0.649	170.06
	74	Brindisi	1.12%	6.57%	170.52	214.08	0.917	0.604	110.96
	75	Lecce	1.91%	9.01%	226.59	288.70	0.924	0.624	63.36
	110	Barletta-Andria-Trani	1.22%	4.38%	205.56	255.20	0.940	0.696	218.25
17	76	Potenza	0.25%	1.37%	68.11	55.84	0.901	0.543	714.37
	77	Matera	0.15%	1.11%	52.97	57.48	0.851	0.598	272.4
18	78	Cosenza	0.71%	2.51%	103.30	106.22	0.821	0.614	622.73
	79	Catanzaro	0.85%	4.16%	154.38	149.83	0.822	0.623	492.76
	80	Reggio di Calabria	1.26%	3.50%	201.11	172.35	0.813	0.635	480.49
	101	Crotone	0.55%	1.96%	83.23	102.03	0.852	0.625	279.05
	102	Vibo Valentia	1.16%	3.36%	181.32	140.53	0.817	0.604	455.38
19	81	Trapani	2.08%	5.14%	168.82	175.18	0.866	0.661	179.2
	82	Palermo	1.36%	3.87%	206.20	251.15	0.875	0.641	538.37
	83	Messina	1.40%	3.73%	205.77	193.44	0.833	0.603	604.02
	84	Agrigento	0.99%	3.84%	155.31	143.12	0.893	0.628	307.75
	85	Caltanissetta	0.88%	2.98%	140.24	123.31	0.888	0.632	336.21
	86	Enna	0.60%	1.79%	94.72	64.32	0.875	0.569	534.81
	87	Catania	1.68%	5.16%	225.27	311.89	0.863	0.638	517.24
	88	Ragusa	1.56%	7.00%	150.97	198.95	0.801	0.622	290.02
	89	Syracuse	1.22%	6.15%	151.33	189.48	0.855	0.680	238.59
20	90	Sassari	0.34%	2.02%	46.21	64.04	0.916	0.621	314.58
	91	Nuoro	0.28%	1.03%	34.66	36.99	0.931	0.596	530.91
	92	Cagliari	1.86%	5.38%	164.54	345.97	0.966	0.678	221.24
	95	Oristano	0.70%	1.69%	54.37	52.76	0.936	0.623	225.74
	111	South Sardinia	0.62%	1.51%	55.10	53.76	0.942	0.618	274.37
IT		Italy	1.83%	4.47%	157.67	200.35	0.870	0.690	-
Mean			2.46%	5.66%	208.40	270.80	0.85	0.66	456.84
Median			1.55%	4.61%	164.54	176.33	0.87	0.65	378.20
Standard deviation			3.04%	4.61%	246.77	383.87	0.09	0.06	371.14

*Tab ii D_p and D_b indices for all Basilicata' municipalities for 5 temporal phases, from 1950 to 2013. The symbol * indicates municipalities that exceed the threshold values that identify urban sprinkling.*

Municipality	**Municipality surface [ha]**	**1950**		**1989**		**1998**		**2006**		**2013**	
		D_p	D_b	D_p	D_b	D_p	D_b	D_p	D_b	D_p	D_b
Abriola	9656.63	0.33	0.06	0.21	0.10	0.19	0.12	0.18	0.13	0.16	0.13
Accettura	8928.09	0.51	0.09	0.31	0.12	0.27	0.12	0.25	0.12	0.22	0.12
Acerenza	7712.77	0.67	0.12	0.39	0.20	0.39	0.21	0.36	0.22	0.33	0.22
Albano di Lucania	5506.07	0.48	0.08	0.31	0.13	0.29	0.14	0.28	0.15	0.27	0.16
Aliano	9633.08	0.24	0.05	0.16	0.09	0.13	0.09	0.12	0.09	0.11	0.09
Anzi	7678.07	0.44	0.07	0.28	0.13	0.25	0.15	0.24	0.15	0.23	0.16
Armento	5852.43	0.35	0.07	0.16	0.11	0.14	0.13	0.13	0.14	0.12	0.14
Atella	8792.14	0.43	0.17	0.40	0.19	0.42	0.21	0.43	0.23	0.44	0.23
Avigliano	8434.20	1.28	0.26	1.39	0.49	1.43	0.54	1.41	0.58	1.40	0.60

Balvano	4170.67	0.69	0.09	0.55	0.22	0.48	0.24	0.46	0.25	0.45	0.26
Banzi	8230.50	0.31	0.07	0.23	0.11	0.18	0.13	0.18	0.13	0.17	0.13
Baragiano	2934.02	0.91	0.17	0.93	0.49	0.94	0.54	0.92	0.56	0.91	0.57
Barile	2462.49	1.75	0.27	1.32	0.50	1.31	0.53	1.25	0.54	1.18	0.58
Bella	9925.78	0.64	0.11	0.58	0.28	0.55	0.31	0.54	0.32	0.53	0.33
Bernalda	12,555.78	0.80	0.13	0.96	0.42	0.95	0.48	0.96	0.50	0.98	0.55
Brienza	8260.70	0.56	0.12	0.50	0.24	0.49	0.28	0.49	0.30	0.49	0.31
Brindisi di Montagna	5971.15	0.33	0.06	0.16	0.09	0.15	0.11	0.15	0.11	0.15	0.12
Calciano	4868.20	0.35	0.07	0.22	0.11	0.18	0.11	0.17	0.12	0.16	0.12
Calvello	10,493.35	0.38	0.07	0.23	0.10	0.21	0.13	0.20	0.13	0.19	0.14
Calvera	1577.84	0.57	0.19	0.42	0.29	0.37	0.30	0.32	0.30	0.27	0.30
Campomaggiore	1222.80	1.03	0.13	0.91	0.33	0.80	0.36	0.75	0.38	0.70	0.41
Cancellara	4209.52	0.66	0.14	0.41	0.19	0.38	0.21	0.36	0.22	0.33	0.22
Carbone	4774.83	0.44	0.09	0.25	0.15	0.18	0.15	0.16	0.16	0.15	0.16
Castelgrande	3443.17	0.88	0.14	0.39	0.32	0.36	0.35	0.33	0.36	0.30	0.37
Castelluccio Inferiore	2878.71	0.88	0.20	0.91	0.35	0.81	0.40	0.79	0.42	0.76	0.43
Castelluccio Superiore	3225.10	0.53	0.15	0.35	0.20	0.31	0.21	0.29	0.22	0.27	0.23
Castelmezzano	3358.64	0.56	0.13	0.32	0.18	0.29	0.21	0.27	0.22	0.25	0.24
Castelsaraceno	7413.35	0.38	0.05	0.27	0.09	0.23	0.09	0.22	0.10	0.20	0.10
Castronuovo Sant`Andrea	4691.81	0.57	0.09	0.36	0.17	0.31	0.18	0.27	0.18	0.24	0.18
Cersosimo	2464.67	0.49	0.11	0.36	0.21	0.34	0.22	0.32	0.24	0.29	0.24
Chiaromonte	6435.16	0.53	0.14	0.37	0.22	0.33	0.25	0.32	0.27	0.30	0.27
Cirigliano	1491.80	0.84	0.15	0.36	0.21	0.30	0.25	0.27	0.25	0.24	0.26
Colobraro	6584.72	0.45	0.08	0.27	0.13	0.23	0.14	0.22	0.14	0.20	0.14
Corleto Perticara	8894.73	0.59	0.10	0.38	0.15	0.34	0.17	0.32	0.18	0.29	0.19
Craco	7624.38	0.24	0.04	0.13	0.08	0.10	0.08	0.10	0.08	0.10	0.08
Episcopia	2871.06	0.63	0.14	0.60	0.28	0.57	0.31	0.54	0.32	0.51	0.32
Fardella	2377.62	0.49	0.14	0.36	0.25	0.32	0.27	0.29	0.28	0.26	0.28
Ferrandina	21,546.85	0.40	0.06	0.44	0.12	0.43	0.14	0.43	0.15	0.42	0.15
Filiano	7125.21	0.53	0.19	0.47	0.31	0.46	0.34	0.45	0.35	0.43	0.36
Forenza	11,552.65	0.51	0.13	0.24	0.14	0.22	0.15	0.21	0.16	0.19	0.16
Francavilla sul Sinni	4592.18	0.88	0.22	0.88	0.44	0.95	0.49	0.94	0.52	0.93	0.54
Gallicchio	2349.62	0.55	0.09	0.48	0.22	0.43	0.25	0.41	0.28	0.38	0.28
Garaguso	3857.40	0.37	0.07	0.33	0.13	0.31	0.14	0.30	0.16	0.29	0.16
Genzano di Lucania	20,676.19	0.41	0.09	0.31	0.16	0.30	0.17	0.29	0.18	0.29	0.18
Ginestra	1318.01	1.34	0.10	0.59	0.14	0.55	0.16	0.56	0.19	0.56	0.20
Gorgoglione	3420.76	0.55	0.09	0.41	0.13	0.34	0.16	0.33	0.16	0.31	0.17
Grassano	4110.76	2.05*	0.24	1.48	0.45	1.41	0.49	1.36	0.51	1.31	0.52
Grottole	11,581.54	0.31	0.11	0.26	0.18	0.23	0.19	0.21	0.19	0.20	0.20
Grumento Nova	6615.43	0.36	0.12	0.30	0.20	0.28	0.23	0.27	0.25	0.26	0.25
Guardia Perticara	5289.04	0.30	0.06	0.15	0.10	0.14	0.11	0.13	0.11	0.11	0.12
Irsina	26,199.01	0.39	0.06	0.25	0.11	0.22	0.12	0.21	0.12	0.19	0.12

Lagonegro	11,231.40	0.55	0.08	0.56	0.16	0.55	0.19	0.53	0.21	0.51	0.23
Latronico	7594.99	0.87	0.22	0.73	0.41	0.70	0.43	0.66	0.45	0.63	0.45
Laurenzana	9510.78	0.50	0.05	0.28	0.09	0.24	0.11	0.22	0.12	0.20	0.12
Lauria	17,552.77	0.68	0.12	0.78	0.24	0.79	0.38	0.77	0.40	0.76	0.41
Lavello	13,274.39	1.11	0.21	1.00	0.29	1.00	0.30	1.01	0.32	1.02	0.33
Maratea	6716.36	0.72	0.32	0.78	0.70	0.78	0.80	0.78	0.84*	0.77	0.86*
Marsico Nuovo	10,010.80	0.60	0.10	0.56	0.23	0.51	0.28	0.47	0.30	0.44	0.31
Marsicovetere	3778.94	0.59	0.14	1.08	0.39	1.24	0.51	1.33	0.59	1.41	0.61
Maschito	4543.59	0.84	0.17	0.43	0.20	0.41	0.22	0.40	0.22	0.38	0.22
Matera	38,757.00	0.78	0.10	1.42	0.30	1.49	0.35	1.52	0.37	1.54	0.44
Melfi	20,512.67	0.87	0.11	0.77	0.23	0.79	0.26	0.82	0.29	0.85	0.30
Miglionico	8886.54	0.48	0.12	0.31	0.20	0.30	0.23	0.29	0.24	0.29	0.24
Missanello	2234.99	0.48	0.05	0.32	0.12	0.27	0.14	0.26	0.15	0.25	0.16
Moliterno	9759.62	0.60	0.12	0.52	0.21	0.47	0.23	0.45	0.25	0.43	0.25
Montalbano Jonico	13,268.06	0.42	0.10	0.65	0.25	0.60	0.26	0.58	0.27	0.56	0.28
Montemilone	11,334.88	0.42	0.07	0.19	0.11	0.18	0.12	0.16	0.12	0.15	0.12
Montemurro	5650.51	0.51	0.15	0.29	0.17	0.28	0.19	0.25	0.20	0.23	0.21
Montescaglioso	17,305.22	0.54	0.10	0.58	0.27	0.58	0.29	0.58	0.32	0.58	0.33
Muro Lucano	12,565.04	0.83	0.18	0.51	0.36	0.49	0.39	0.46	0.41	0.44	0.42
Nemoli	1972.91	0.86	0.21	0.81	0.47	0.79	0.51	0.78	0.55	0.77	0.56
Noepoli	5154.26	0.44	0.08	0.26	0.13	0.23	0.15	0.21	0.16	0.19	0.16
Nova Siri	5224.77	0.73	0.11	1.13	0.47	1.23	0.55	1.25	0.59	1.26	0.61
Oliveto Lucano	3145.18	0.42	0.09	0.24	0.14	0.19	0.15	0.17	0.15	0.16	0.16
Oppido Lucano	5468.81	0.83	0.19	0.73	0.35	0.73	0.38	0.72	0.41	0.71	0.44
Palazzo San Gervasio	6222.61	1.41	0.27	0.99	0.36	0.83	0.38	0.82	0.38	0.81	0.44
Paterno	4006.38	0.82	0.18	1.04	0.51	1.00	0.62	0.93	0.66	0.85	0.69
Pescopagano	6902.60	0.61	0.18	0.35	0.21	0.31	0.24	0.30	0.24	0.29	0.25
Picerno	7822.46	0.73	0.17	0.76	0.39	0.79	0.44	0.78	0.50	0.78	0.52
Pietragalla	6560.25	0.94	0.19	0.71	0.33	0.69	0.36	0.67	0.38	0.65	0.39
Pietrapertosa	6719.45	0.35	0.09	0.22	0.13	0.20	0.14	0.18	0.14	0.16	0.16
Pignola	5548.97	0.68	0.12	0.84	0.35	0.99	0.46	1.10	0.55	1.21	0.61
Pisticci	23,187.35	0.64	0.13	0.79	0.45	0.77	0.47	0.76	0.49	0.75	0.49
Policoro	6760.61	0.13	0.03	2.15*	0.65	2.23*	0.70	2.30*	0.77	2.36*	0.89*
Pomarico	12,846.33	0.45	0.07	0.39	0.17	0.35	0.19	0.34	0.20	0.33	0.20
Potenza	17,383.69	1.87	0.19	3.78*	0.70	3.97*	0.83*	3.91*	0.86	3.84*	0.89*
Rapolla	2903.65	1.53	0.19	1.53	0.47	1.60	0.54	1.56	0.57	1.53	0.58
Rapone	2910.57	0.78	0.25	0.46	0.29	0.41	0.31	0.38	0.32	0.35	0.32
Rionero in Vulture	5312.38	2.78*	0.62	2.48*	0.82*	2.53*	0.89*	2.53*	0.96*	2.53*	0.98*
Ripacandida	3320.90	1.52	0.21	0.62	0.23	0.53	0.27	0.53	0.29	0.52	0.32
Rivello	6889.48	0.57	0.24	0.46	0.38	0.44	0.41	0.42	0.43	0.41	0.44
Roccanova	6164.20	0.43	0.07	0.33	0.13	0.29	0.15	0.28	0.16	0.27	0.16
Rotonda	4227.80	1.03	0.29	0.95	0.57	0.92	0.61	0.88	0.66	0.83	0.70
Rotondella	7637.74	0.73	0.10	0.49	0.12	0.42	0.22	0.39	0.22	0.35	0.22
Ruoti	5501.51	0.75	0.12	0.69	0.34	0.67	0.38	0.66	0.40	0.64	0.43
Ruvo Del Monte	3218.40	0.97	0.13	0.45	0.14	0.39	0.19	0.37	0.26	0.34	0.27

Salandra	7709.52	0.51	0.11	0.44	0.19	0.40	0.21	0.39	0.22	0.38	0.22
San Chirico Nuovo	2314.83	0.94	0.19	0.78	0.30	0.71	0.32	0.67	0.33	0.64	0.34
San Chirico Raparo	8295.71	0.39	0.07	0.20	0.11	0.16	0.12	0.15	0.12	0.14	0.12
San Costantino Albanese	3742.10	0.47	0.15	0.29	0.21	0.24	0.22	0.22	0.23	0.21	0.23
San Fele	9667.11	0.82	0.15	0.43	0.24	0.40	0.28	0.36	0.30	0.33	0.31
San Giorgio Lucano	3893.14	0.74	0.14	0.47	0.21	0.39	0.24	0.36	0.25	0.33	0.26
San Martino D`Agri	5027.65	0.33	0.08	0.25	0.14	0.19	0.15	0.18	0.16	0.16	0.16
San Mauro Forte	8664.87	0.43	0.07	0.35	0.11	0.27	0.12	0.23	0.13	0.20	0.13
San Paolo Albanese	2986.41	0.31	0.11	0.18	0.17	0.14	0.18	0.12	0.18	0.10	0.19
San Severino Lucano	6172.96	0.56	0.14	0.36	0.20	0.31	0.22	0.29	0.23	0.27	0.24
Sant Arcangelo	8945.71	0.71	0.08	0.81	0.20	0.74	0.23	0.73	0.25	0.73	0.26
Sant`Angelo le Fratte	2296.94	0.89	0.24	0.72	0.44	0.64	0.52	0.64	0.56	0.63	0.57
Sarconi	3044.78	0.44	0.13	0.43	0.25	0.44	0.28	0.45	0.31	0.45	0.32
Sasso Di Castalda	4517.29	0.31	0.08	0.25	0.16	0.19	0.18	0.19	0.19	0.18	0.20
Satriano Di Lucania	3295.15	0.88	0.28	0.74	0.48	0.71	0.54	0.72	0.58	0.73	0.60
Savoia Di Lucania	3224.99	0.55	0.14	0.42	0.26	0.38	0.29	0.37	0.31	0.36	0.32
Scanzano Jonico	7066.94	0.47	0.03	0.88	0.43	0.95	0.48	0.98	0.52	1.01	0.54
Senise	9656.80	0.73	0.11	0.76	0.25	0.74	0.28	0.74	0.29	0.74	0.30
Spinoso	3779.12	0.63	0.19	0.49	0.21	0.47	0.25	0.44	0.27	0.41	0.28
Stigliano	20,979.56	0.46	0.10	0.31	0.13	0.27	0.14	0.25	0.14	0.22	0.15
Teana	1961.22	0.56	0.18	0.45	0.31	0.38	0.33	0.36	0.34	0.33	0.34
Terranova di Pollino	11,226.81	0.24	0.06	0.16	0.09	0.14	0.10	0.13	0.10	0.12	0.11
Tito	7059.52	0.60	0.12	0.81	0.29	0.90	0.35	0.96	0.39	1.02	0.44
Tolve	12,762.48	0.43	0.05	0.30	0.09	0.28	0.10	0.27	0.10	0.26	0.11
Tramutola	3647.36	0.95	0.18	0.89	0.36	0.89	0.46	0.88	0.52	0.87	0.53
Trecchina	3767.59	0.71	0.27	0.67	0.46	0.64	0.49	0.63	0.52	0.62	0.54
Tricarico	16,469.80	0.58	0.08	0.43	0.16	0.38	0.18	0.36	0.18	0.34	0.19
Trivigno	2592.26	0.73	0.11	0.33	0.18	0.31	0.20	0.29	0.21	0.28	0.22
Tursi	15,675.66	0.39	0.06	0.38	0.15	0.35	0.16	0.34	0.17	0.33	0.17
Vaglio Basilicata	4292.15	0.66	0.13	0.54	0.25	0.52	0.29	0.50	0.31	0.48	0.32
Valsinni	3201.59	0.83	0.16	0.61	0.25	0.56	0.27	0.54	0.27	0.51	0.27
Venosa	16,920.02	0.79	0.09	0.70	0.17	0.72	0.19	0.72	0.19	0.72	0.24
Vietri di Potenza	5197.91	0.68	0.15	0.63	0.30	0.60	0.33	0.58	0.34	0.56	0.35
Viggianello	11,976.64	0.46	0.11	0.33	0.21	0.29	0.23	0.28	0.24	0.26	0.25
Viggiano	8893.75	0.47	0.09	0.36	0.17	0.36	0.19	0.36	0.20	0.35	0.21

Tab iii Landscape fragmentation indices for the years 1990, 2000, 2012 and 2018 for each land cover class.

	Class	Residential building	Industrial and commercial building	Extensive agricolture	Intensive agricolture	Forests	Bare soils	Arbustive soils	Grass land	Weatland	Wather	Beaches and dunes	RES
	Year/Code	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Land cover [sq.km]	*1990*	130.28	245.45	1573.39	3923.54	2872.91	87.37	425.57	632.01	2.06	27.97	63.46	-
	2000	150.15	248.50	1400.02	3985.97	2837.09	131.37	589.82	528.04	11.28	26.56	75.20	-
	2012	182.45	245.76	1295.05	4107.36	2752.31	214.84	713.08	358.26	9.07	34.53	68.93	1.76
	2018	185.91	246.67	1292.93	4100.21	2749.77	215.00	718.33	356.45	9.08	34.53	68.96	6.17
Landscape Proportion	*1990*	1.30%	2.46%	15.76%	39.30%	28.78%	0.88%	4.26%	6.33%	0.02%	0.28%	0.64%	-
	2000	1.50%	2.49%	14.02%	39.92%	28.42%	1.32%	5.91%	5.29%	0.11%	0.27%	0.75%	-
	2012	1.83%	2.46%	12.97%	41.14%	27.57%	2.15%	7.14%	3.59%	0.09%	0.35%	0.69%	0.02%
	2018	1.86%	2.47%	12.95%	41.07%	27.54%	2.15%	7.19%	3.57%	0.09%	0.35%	0.69%	0.06%
Edge length [km]	*1990*	13,964	98,275	37,469	55,093	36,446	1218	7074	9350	30	166	1409	-
	2000	16,173	98,529	36,413	57,631	36,461	1811	9547	8093	187	178	1649	-
	2012	18,850	98,698	33,945	60,695	35,116	2749	11,359	5473	128	213	1542	110
	2018	19,160	98,931	33,982	61,146	35,124	2767	11,437	5471	128	213	1544	481
Largest Patch Index	*1990*	0.059	0.190	0.311	15.352	2.656	0.045	0.066	0.205	0.013	0.091	0.053	-
	2000	0.060	0.140	0.290	15.620	1.990	0.060	0.080	0.190	0.030	0.080	0.050	-
	2012	0.065	0.180	0.305	14.743	2.590	0.098	0.183	0.132	0.022	0.099	0.051	0.001
	2018	0.068	0.236	0.319	12.577	1.767	0.098	0.184	0.132	0.021	0.099	0.051	0.001
Edge density	*1990*	0.14%	0.98%	0.38%	0.55%	0.37%	0.01%	0.07%	0.09%	0.30%	0.17%	0.01%	-
	2000	0.16%	0.99%	0.36%	0.58%	0.37%	0.02%	0.10%	0.08%	0.19%	0.18%	0.02%	-
	2012	0.19%	0.99%	0.34%	0.61%	0.35%	0.03%	0.11%	0.05%	0.13%	0.21%	0.02%	0.11%
	2018	0.19%	0.99%	0.34%	0.61%	0.35%	0.03%	0.11%	0.05%	0.13%	0.21%	0.02%	0.48%
Number of Patches	*1990*	54,508	931,550	13,877	10,303	5762	223	1931	1766	21	29	623	-
	2000	61,184	933,627	15,409	10,254	5902	381	2232	1667	82	43	647	-
	2012	66,956	935,385	14,021	12,085	5730	514	2735	1010	48	38	659	368
	2018	67,882	942,198	14,192	12,049	5751	531	2778	1022	45	38	650	2326
Splitting Index	*1990*	1.515	0.103	0.017	0.000	0.001	0.733	0.163	0.028	53.336	0.715	0.792	-
	2000	1.178	0.129	0.024	0.000	0.001	0.508	0.099	0.053	5.199	0.827	0.696	-
	2012	0.801	0.103	0.028	0.000	0.001	0.184	0.052	0.080	8.060	0.472	0.743	2796.36
	2018	0.877	0.080	0.027	0.000	0.001	0.179	0.052	0.079	8.657	0.472	0.741	950.58

Glossary

De-sealing: the de-sealing procedure concerns the restoration of the previously sealed part of the soil by removing the impermeable material that covers it such as asphalt or concrete, tilling the underlying soil, removing foreign material and restructuring its profile. The goal is to recover a real connection with the natural subsoil (European Commission, 2012 [29]).

De-sprinkling: slackening, up to the interruption, of the phenomena of further land take according to traditional dynamics, so as not to further burden the current conditions. It is an action reasonably falling within the Regions' strategic responsibilities. In this sense, the laws pertaining to "land consumption," with which several Regions have already complied, seem to be the main solution for setting regulatory fiscal regulations aimed at containing the behaviours of municipalities and private subjects as to further forms of uncontrolled use of territorial surfaces [19].

De-sprawling: A European de-sprawling strategy can consist of monitoring urban sprawl to document landscape change, to compare regional territories and identify sprawl hotspots, to estimate rates of change, and to detect principal trends. Establish quantitative targets, limits, and benchmarks to control urban sprawl and performance monitoring implementation for anti-sprawl policies. Effectively protect the remaining large undeveloped areas and areas sensitive to sprawl. Establish clear boundaries delineating the extent of built-up area from undeveloped areas and limiting the amount of new buildable area designated. Long-term and large-scale settlement planning based on guiding principles for landscape management to strengthen cooperation among municipalities. Establish economic instruments, which compensate for increased property values as a result of planning, development and infrastructure [46].

Fragmentation the breaking up of extensive landscape features into disjunct, isolated, or semi-isolated patches as a result of land-use changes (EEA, glossary [40]).

Functional urban area: the functional urban area (FUA) consists of the city and its commuting zone'. Functional urban areas therefore consist of a densely inhabited city and a less densely populated commuting zone whose labour market is highly integrated with the city (EUROSTAT glossary [110]).

Habitat fragmentation habitat fragmentation is defined as the process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area isolated from each other by a matrix of habitats unlike the original [237]

Landscape fragmentation landscape fragmentation is the breaking up of larger areas of natural land cover into smaller, more isolated patches, independent of a change in the total area of natural land cover (EEA, glossary [40]).

Land densification is defined as the land development that takes place within existing communities, making maximum use of the existing infrastructure instead of building on previously undeveloped land (EEA, glossary [40]).

Land consumption: consumption of land cover means: (a) The expansion of built-up area which can be directly measured; (b) the absolute extent of land that is subject to exploitation by agriculture, forestry or other economic activities; and (c) the over-intensive exploitation of land that is used for agriculture and forestry [40].

Land take: a) the area of land that is *taken* by infrastructure itself and other facilities that necessarily go along with the infrastructure, such as filling stations on roads and railway stations (source 1999, EEA Glossary [40])

b) also referred to as land consumption describes an increase of settlement areas over time. This process includes the development of scattered settlements in rural areas, the expansion of urban areas around an urban nucleus (including urban sprawl), and the conversion of land within an urban area (densification). Depending on local circumstances, a greater or smaller part of the land take will result in actual soil sealing [29].

c) the amount of agriculture, forest, semi-natural/natural land, wetlands or water taken by urban and other artificial land development, as defined in the EEA Land take indicator (CSI 014/LSI 001; EEA, 2005). This indicator provides information on the change from agricultural, forestry and semi-natural/ natural land, wetlands or water to urban land cover as a consequence of urban residential development, development of economic sites and infrastructures (including the creation of industrial, commercial and transport units, but excluding the conversion of previously developed land to sport and leisure facilities) and development of green urban areas on previously undeveloped land. To this end, the indicator uses Corine Land Cover (CLC) data, containing a hybrid of land cover and land use data. Land take is also referred to as 'land consumption' in some cases, although the actual meaning may differ from the EEA's definition of land take [41].

Soil sealing: the permanent covering of an area of land and its soil by impermeable artificial material (e.g. asphalt and concrete), for example through buildings and roads' (EC, 2012, p. 36) or 'the covering of the soil surface with impervious materials as the result of urban development and infrastructure construction', as defined in the EEA Imperviousness indicator (EEA, glossary [40]).

Urbanization: is a process of global scale changing the social and environmental landscape on every continent. Urbanization is a result of population migration from rural areas in addition to natural urban demographic growth. In 2007, the world's population living in towns and cities surpassed 50% for the first time in history and this proportion is growing. Rapid, unplanned and unsustainable patterns of urban development are making developing cities focal points for many emerging environment and health hazards. As urban populations grow, the quality of global and local ecosystems, and the urban environment, will play an increasingly important role in public health with respect to issues ranging from solid waste disposal, provision of safe water and sanitation, and injury prevention, to the interface between urban poverty, environment and health (World Healt Organization – WHO [236]).

Urban area: areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial or recreational purposes (EEA, glossary [40]).

Urban fragmentation is related to morphological changes in urban areas and their consequent dispersion in space [116].

Urban Sprawl: a) urban sprawl is a phenomenon that can be visually perceived in the landscape. A landscape suffers from urban sprawl if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high. The more area built over and the more dispersed the build-up area, and the higher the land uptake per inhabitant or job (lower utilization intensity in the built-up area), the higher the degree of urban sprawl" [41,42].

b) The physical pattern of low-density expansion of large urban areas under market conditions into the surrounding agricultural areas. Sprawl lies in advance of the principal lines of urban growth and implies little planning control of land subdivision. Development is patchy, scattered and strung out, with a tendency to discontinuity because it leap-frogs over some areas, leaving agricultural enclaves [40].

Urban Shrinkage refers to a concomitant process of demographic and economic decline with a structural impact on two constitutive elements of the city, the density of the population and its economic functions, thus generating considerable social effects [126].

Urban Sprinkling: a small quantity distributed in drops or scattered particles [18].

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- Curatella, L., Fortunato, G., Pilogallo, A., Saganeiti, L., Santarsiero, V., Bonifazi, A., & Scorza, F. (2021). **"Polycentrism and effective territorial structures: Basilicata region case study."** *In: Bevilacqua C., Calabrò F., Della Spina L. (eds) New Metropolitan Perspectives. NMP 2020. Smart Innovation, Systems and Technologies, vol 178, 1689–1696*. DOI: https://doi.org/10.1007/978-3-030-48279-4_159

- Scorza, F., Murgante, B., Pilogallo, A., Saganeiti, L., Santarsiero, V., Faruolo, G., Fortunato, G., Izzo, C., Piro, R., & Bonifazi, A. (2021). **"Best practices of agro-food sector in basilicata region (italy): Evidences from innovagro project."** *In: Bevilacqua C., Calabrò F., Della Spina L. (eds) New Metropolitan Perspectives. NMP 2020. Smart Innovation, Systems and Technologies, vol 178, 1706–1713.* DOI: https://doi.org/10.1007/978-3-030-48279-4_161

- Bentivenga, M., Bellanova, J., Calamita, G., Capece, A., Cavalcante, F., Gueguen, E., Guglielmi, P., Murgante, B., Palladino, G., Perrone, A., Saganeiti, L., & Piscitelli, S. (2020). **"Geomorphological and geophysical surveys with InSAR analysis applied to the Picerno earth flow (southern Apennines, Italy)."** *Landslides, 1–13*. DOI: https://doi.org/10.1007/s10346-020-01499-z **IF: 4.708**

Other papers on international and national peer reviewed journals indexed on Scopus and/or of A level in ANVUR ranking 2020 (ICAR/20) during the 2017 year.

2017

- Bentivenga, M., Giano, S. I., Saganeiti, L., Nolè, G., Palladino, G., Prosser, G., & Murgante, B. (2017). **"Deep-seated gravitational slope deformation in urban areas matching field and in-SAR interferometry surveys: The case study of the Episcopia village, southern Italy."** *In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 10407 LNCS*. DOI: https://doi.org/10.1007/978-3-319-62401-3_48

- Saganeiti, L., Amato, F., Potleca, M., Nolè, G., Vona, M., & Murgante, B. (2017). **"Change detection and classification of seismic damage with LiDAR and RADAR surveys in supporting emergency planning. The case of amatrice."** *In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 10407 LNCS.* DOI: https://doi.org/10.1007/978-3-319-62401-3_53

- Saganeiti, L., Amato, F., Murgante, B., & Nolè, G. (2017). **"VGI and crisis mapping in an emergency situation. Comparison of four case studies: Haiti, Kibera, Kathmandu,**

Centre Italy." *GEOmedia, 21(3)*. DOI: http://ojs.mediageo.it/index.php/GEOmedia/article/view/1445/1320

Visiting PhD student

2019

LEMA lab (Local Environment Management & Analysis) Université de Liège - Faculté des Sciences Appliquées Section d'Architecture, Liege (Belgium) https://www.uee.uliege.be/cms/c_4518224/en/lema Research activities aimed at the application of an urban expansion simulation model with multi-density approach. Simulation with cellular automata and multi-logistic regression model.

Participation at national and international conferences

2018

- **"23rd International Conference on Urban Planning and Regional Development in the Information society – REAL CORP 2018"**. *Expanding cities – Diminishing space". TU Wien Austria*.
- National conference**: "Il patrimonio geologico: dallo studio di base al geoturismo sostenibile".** *Potenza, Italy.*
- International conference "**NMP - 2018: New Metropolitan Perspectives - Local Knowledge and innovation dynamics towards territory attractiveness through the implementation of Horizon / E2020"** *Reggio Calabria, Italy.*
- International conference **"ICCSA 2018 – The Annual International Conference on Computational Science and its Applications"**, *Monash University in Melbourne, Australia*.

2019

- International conference: **"REAL CORP 2019 International Conference on Urban Planning and Regional Development in the Information Society".** *Karlsruhe, Germany.*
- **"CeNSU International Annual Symposium"**, *Densità e sostenibilità, Naples (Italy)*
- **"Urbing phd"**, *Rome, Italy.*
- International conference: **"ICCSA 2019 - International Conference on Computational Science and Applications"**, *St. petersburg (Russia).*
- International conference: **"The European Colloquium on Theoretical and Quantitative Geography - ECTQG 2019"**, *Mondorf les Bains, Luxemburg.*
- XXIV International Conference **"Living and Walking in Cities"**, *Brescia, Italy.*

2020

- National conference: **"EGU general assembly – European Geosciences Union"**. *On-line conference.*

- International conference “**NMP - 2020: New Metropolitan Perspectives.”** *On-line conference.*
- International conference: **“ICCSA 2020 - International Conference on Computational Science and Applications”**. *On-line conference.*

Summer school

2018

- Summer school **“DeepLearn 2018 - International Summer school on Deep Learning”** University of Genova and IRDTA Brussels – London. *Locality Genova, Italy*.
- Summer school **“ERA4CS summer school – Climate services from the user’s perspective”**. *CNR Research Area of Pisa – Pisa, Italy*.

Personal metrics

ORCID: https://orcid.org/0000-0001-9361-8931

Scopus

Number of published documents: 34
Number of citations: 178 by 69 documents
h-index: 5 excluding self-citations
Number of co-authors: 45

Google scholar

Number of published documents: 39
Number of citations: 190
h-index: 8