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A Decision Support Methodology to Foster Renewable Energy Communities in the Municipal Urban Plan

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Abstract: Renewable Energy Communities (RECs) represent a possible solution to facilitate the transition to carbon neutrality and reduce energy poverty in urban areas. Although the topic has received little attention from urban planning scholars and practitioners, they can make a significant contribution in the enhancement of RECs. To this end, this article proposes a methodology that allows identifying priority urban areas where the Municipal Urban Plan can incentivize RECs' establishment. These areas are spatially identified where a minimization of the constraints on RECs' formation and a maximization of their energy and social benefits are expected. The application of the proposed methodology to an Italian municipal area where the Plan is being drawn up is presented. The obtained results show how priority areas can be found both in the urban center and in rural areas, suggesting that urban planning can encourage different REC configurations, depending on the settlement fabric and land use, as well as the number of buildings to be clustered and potential leaders who can lead the community development process.

Keywords: renewable energy communities; energy poverty; urban planning

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1. Introduction

The need to contain the global average temperature is remarked upon by a multitude of international agreements and agendas [1,2]. While the recent pandemic has increased poverty in general, the rising energy prices risk significantly worsening energy poverty.

Although a shared definition of energy poverty is lacking in the international scientific community, according to the European Commission (EC) it represents "a situation where a household or an individual is unable to afford basic energy services (heating, cooling, lighting, mobility and power) to guarantee a decent standard of living due to a combination of low income, high energy expenditure and low energy efficiency of their homes" [3]. Based on another commonly accepted definition, energy poverty occurs when individuals or vulnerable sectors of the population face difficulty in adequately heating their homes. In fact, among the primary energy services, the greatest domestic consumption derives from heating and domestic hot water production [4,5].

EC estimated that in the European Union (EU), energy poverty affected up to 31 million people in 2019, with persistent differences between Member States and income levels [6]. In Italy, in the same year, the percentage of people with difficulty in adequately heating their homes was double the European average [7]. In this context, it is crucial to protect vulnerable people from the current price hike and to ensure a just transition towards climate neutrality in the entire EU [6].

Urban planning cannot fail to take into account these needs, which are to be placed among its primary objectives [2,8].

According to the European Commission definition, a Renewable Energy Community (REC) is "an autonomous legal entity (. . .) based on open and voluntary participation of natural persons, SMEs or local authorities, including municipalities, (. . .) located in the proximity of the renewable energy projects that are owned and developed by that legal entity, (. . .) the primary purpose of which is to provide environmental, economic or social community benefits for its (. . .) members or for the local areas where it operates, rather than financial profits" [9]. In other words, REC members can produce clean energy and offer others the amount of energy they do not need for their own consumption, on the basis of a statute approved by all participants.

The results of some REC experiments conducted in Europe and the United States have led to a growing interest in the topic, in terms of RECs reducing energy poverty, as well as contributing numerous environmental benefits, including: the greater use of energy from renewable sources (RES); the increase in social acceptance of RES plants; the improved energy efficiency of existing buildings; the reduction of climate-altering emissions; and the contrast to climate change in urban areas [10–12].

With the relevant legislation, Directive EU/2001/2018 (RED II), the European Commission obliges Member States to proceed with an assessment of the existing obstacles to and the potential for REC development in their territories, providing an adequate support framework to promote and facilitate them [9].

This result is the most recent outcome of an ongoing legislative process of reforms to the European internal energy market. However, the idea of cooperation between consumers and local production from renewable sources is already inherent in previous European directives [13].

In this process, the "Clean Energy for all Europeans" regulatory package is crucial, since consumers are declared as "active and central players in the energy markets of the future" and encouraged to also be energy producers, or, in other terms, prosumers.

Along this line, another European directive worthy of mention is the EU/944/2019, which introduces the concept of Citizen Energy Communities (CECs), defined in a similar way to RECs. The main difference is that CECs only respond to the demand for electricity. Moreover, they are not bound to local RES, since CECs can also use fossil-fuel-based energy sources, not necessarily located in close proximity [14,15].

The link between RECs and the local areas where they operate, which is therefore a link with the neighborhoods or urban districts to which they must provide the aforementioned benefits, establishes the main difference between RECs and CECs, which are independent of spatial concerns. This link makes RECs relevant tools for achieving the above-mentioned urban planning objectives.

In this vein, their promotion through urban planning can be included among 'top-down' initiatives to encourage the development of RECs. In fact, if 'bottom-up' actions are launched by citizens themselves, top-down strategies are initiated by an institution or a private company that leads the process and facilitates citizens' involvement [16].

1.1. Renewable Energy Communities and Urban Planning

As possible members of the RECs, municipalities represent potential institutional leaders in the activation of new renewable energy communities. Furthermore, since municipal planning is their responsibility, it can be a non-negligible tool in promoting RECs in order to pursue a sustainable energy transition [17].

However, following this path requires an understanding of how urban planning can promote the development of RECs, according to the European regulatory framework.

To this end, we consulted the existing literature with the help of Scopus and Web of Science search engines, using *energy communities AND urban planning* as keywords. Subsequently, the selected studies were those in which the concept of energy community is understood as defined by the European Directive RED II, even if not expressly stated, and the survey scale is infra-urban, consistent with the purposes of municipal planning.

Among the chosen studies, almost all the works concern the search for optimal spatial configurations of RECs, in order to support urban planners. Furthermore, the energy and technological aspects are predominant in the delimitation of the boundaries of potential energy communities.

In fact, Huang et al. reviewed the development of research on methods and tools for energy planning at community scale, merging the studies with reference to the following three topics: prediction of energy demand; assessment of renewable energy resources; and optimization of the energy system [18].

Among the studies of Italian researchers along this line, the work of Colombo et al. proposes a tool that, applied to a certain area, evaluates from time to time how many buildings to group in energy communities, depending on whether the following objective is achieved: the best solution is the one that is guaranteed to minimize the amount of energy purchased and to store the energy necessary to be self-sufficient for a long time, before experiencing the need to buy it. The proposed tool is tested in a selected area close to the city of Turin [19].

With particular reference to the existing urban fabric, some studies belonging to this trend focus on photovoltaic (PV) technology, showing its advantages in use at the energy community level compared to the scale of a single building [20–23]. In the Italian geographical context, the work of Todeschi et al. defines a model for the optimal design of grid-connected PV–battery systems in urban environments, in order to evaluate the technical feasibility of combining multiple residential users in an energy community. The methodology is applied to two districts located in the city of Turin [24].

Always in the context of this trend, among the recent studies, the use of performance-based planning is frequently proposed. The research of Zwickl-Bernhard and Auer examines different energy supply options for an energy community in Vienna, Austria, using performance indicators to reveal their respective strengths/weaknesses, with the main goal of investigating the optimal energy technology portfolio of an urban neighborhood, so that the latter can exploit its local renewable generation potential to cover its electricity, heat, and cooling demand [25]. The work of Walnum et al. presents a scenario calculator for the development of local smart energy communities in Norway, proposing a tool based on Key Performance Indicators, focusing on energy aspects [26].

Other works focus on the economic aspects, rather than on the energy and technological ones. The work of Volpato et al. identifies general guidelines for the optimal economic aggregation of prosumers, using a procedure for the weight assessment of selected aspects affecting the economic convenience of energy communities [27]. The study of Fleischhacker et al. aims to quantify the advantages of optimizing the technology portfolio of ECs regarding cost and carbon emission reduction, while also paying particular attention to environmental aspects [28].

Few works investigate the aspects more properly connected to urban planning. In this vein, the research of De Lotto et al. aims at defining a management framework to secure and maximize energy autarky, i.e., grid independence and direct profit for prosumers, optimizing the process of energy production and consumption at local scale. The study, applied to some urban districts within the municipal territory of Segrate, in Lombardy Region, Italy, is carried out considering that the provision of the energy communities and their organizational structure must be consistent with the land use and rules set out in the current city plan [29].

Along the same lines, the work of Brunetta et al. proposes a protocol to measure the performance of energy communities, in order to evaluate their contribution to the sustainable development of the territories. Performance is measured with reference to indicators relating to five categories: social, environmental, economic, energy, and territorial. The protocol is applied to the energy community of the Pinerolo area, made up of about thirty municipalities belonging to the Piedmont Region, in Italy. Although referring to territorial energy planning and not to urban planning, this work, in relation to municipal urban planning tools, proposes that reward rules could be introduced, in order to guarantee the achievement of the aforementioned performance [30]. The work by Curreli and Zoppi examines the governance model underlying the energy community of Berchidda, an Italian municipality in the Sardinia Region [31]. This municipality is selected by the Region itself as a priority area in which to experiment with the creation of a local Smart Grid, the technological aspects of which are illustrated in the study by Ghiani et al. [32]. The analysis of the "Berchidda model" in the contribution of Curreli and Zoppi aims to identify best practices to promote energy communities through the regional energy plan. Furthermore, in this case, although the reference to urban planning is not explicit, the proposal of a multidisciplinary and integrated approach to the energy issue is relevant.

1.2. Regulatory Aspects of Renewable Energy Communities in Italy

In the Italian regulatory context, RECs were introduced before the European directive transposition, with the Decree-Law of 30 December 2019, n. 162, in line with the policies promoted by the Integrated National Energy and Climate Plan [33]. The Decree was converted into law on 28 February 2020, with Law no. 8, which specified the spatial–technological and power constraints for the RECs establishment. More precisely, Article 42-bis clarified the essential requirements for the definition of the communities' potential perimeters:

- the consumer withdrawal points and the entry points of plants are located on low-voltage electricity grids, underlying the same secondary transformer substation;
- the participants produce energy by renewable sources for their own consumption, with plants with a total power not exceeding 200 kW.

This regulatory framework was recently updated by Legislative Decree 8 November 2021 n. 199, which transposed the European directive on the subject. It modified the previous parameters, making the imposed requirements less stringent: the connection limit passes from the secondary to the primary transformer substation, allowing a higher number of users to be involved; the power limit is extended from 200 kW to 1 MW.

Some exceptions to the power and connection limits, which may be higher than those mentioned above, are provided exclusively for the Ministry of Defense and the Port Authorities, following the enactment of Legislative Decree 17 May 2022, n. 50. Although these constraints exist for the sole purpose of obtaining economic incentives, the latter are crucial in a context where energy poverty is increasing.

The National Regulatory Authority for Energy, Networks and the Environment (ARERA), which is entrusted with the definition of the implementation rules, plans to conclude by 2023 the procedures necessary to regulate the aspects of its competence. ARERA has also clarified that no intervention by the authority is necessary regarding the sharing of energy forms other than electricity and deriving from renewable sources [34].

Anticipating the REDII European directive transposition, which took place only last November 2021 with the aforementioned Decree 199/2021, some Italian Regions have legislated on RECs, recognizing their potential social, environmental, and economic benefits and providing funding for experimentation with them as a priority in the most disadvantaged areas. This is the case of the Piedmont Region, the Apulia Region, and the Liguria Region [35–37].

Renewable energy communities are recalled also in the National Recovery and Resilience Plan (PNRR), known as 'Next Generation Italy', which reserves a specific investment channel for RECs in the most disadvantaged areas, understood as the municipalities with a population of fewer than 5000 inhabitants [38].

Despite the efforts made by both the central government and the Regions, even in advance of the times dictated by the European directive, the entire Italian territory contains little more than twenty RECs. Moreover, they are concentrated in Northern Italy [39]. As already reported by both academic scholars and well-known environmental associations, the rapid development of RECs is mainly limited by the national legislative and regulatory framework on the issue, which is still partial. In particular, the following factors are considered critical to address: the exclusion of large companies, which, on the contrary, could give greater impetus to the development of the community model; the time required for ARERA to adopt the implementation rules; and the sharing of energy through existing plants.

Sometimes, urban planning is listed among the obstacles to the diffusion of RECs. It is generally believed that urban planning is not up-to-date on the subject, and consequently, there are possible limitations and delays in the authorization process [29,33].

In fact, the sporadic Italian cases of RECs formed up until now had not been foreseen in the urban plans of the municipalities in which they are located. Exceptions are the recent sectoral planning tools, related to energy and climate, of some large cities [40–42]. Even in these cases, with respect to RECs, it is not explicit how these tools relate to the general urban plan.

1.3. Research Gaps and Objectives of the Work

From the analysis of the current state of affairs, summarized in the previous points, it is possible to extract some gaps in the research conducted so far on the topic addressed:

- In the international context, most of the scientific studies deal with the aspects related to energy planning, while those related to urban planning have received little attention;
- In the aforementioned studies, the issue of energy poverty is little investigated in identifying the optimal configurations for the development of potential renewable energy communities;
- Except for a few cases still being implemented, in Italian urban planning, the topic of RECs is scarcely explored.

With reference to the last point, according to some scholars, it depends not only on the incomplete regulatory framework but also on the difficult integration between energy planning and city planning [31,43]. On the contrary, an integrated approach can reduce the risk that outdated planning in relation to the issue of RECs could represent a further obstacle to their rapid diffusion in Italy.

This could partly be the reason why, even in the scientific literature, the topic of RECs is little explored with reference to urban planning, referring back to the first point. The studies analyzed focus on sectoral aspects, while the integration of urban planning factors can encourage a greater development of RECs.

In relation to the second point, in a general context where the economic crisis and the pandemic have led to a general impoverishment of the global population, this aspect cannot be overlooked. It has already been stated that an effective strategy for reducing energy poverty is to encourage area-based initiatives, i.e., to intervene where there is greater need [44]. The promotion of RECs through urban planning could be part of the area-based policies for the reduction of energy poverty. With reference to the Italian context, in this way, it is also possible to intercept economic loans, directed to the most disadvantaged areas, in accordance with the Italian regulatory framework on RECs. However, it should be noted that assessing urban areas characterized by greater energy poverty on an infra-urban scale is not straightforward.

Indeed, the lack of a shared definition of energy poverty, both in Europe and in the international scientific community, determines the absence of an agreement regarding its conceptualization and assessment at the various spatial scales [5].

This work aims to fill the above-mentioned gaps. For this purpose, the present article proposes a model that allows building a map of priority areas, on an infra-urban scale, for the development of RECs through Italian urban planning. Priority areas are those where a minimization of the constraints on RECs' formation and a maximization of their energy and social benefits against energy poverty are expected. This is the main novelty of the work.

This study is part of an ongoing research project, aimed more generally at identifying methods for implementing the promotion of RECs by urban planning. Alongside this project, the same authors presented a preliminary model in a previous conference paper [45]. The model proposed in this article is the result of a refinement of the previous one, following a further study conducted by the authors as part of the project [46].

Therefore, Section 2 below explains the rationale adopted for the proposed methodological path, described in the same section. Section 3 illustrates the case study chosen for the application of the presented methodology, the results of which are shown in Section 4 and discussed in Section 5. Finally, Section 6 reports the main conclusions of the research and possible future developments of the work.

2. Materials and Methods

2.1. Rationale

As mentioned in the Introduction section, European Member States are obliged to proceed with an assessment of the existing obstacles to and the potential for REC development in their territories, providing an adequate support framework to promote and facilitate them, according to the EU Directive "RED II".

With this in mind, our work proposes a methodology that allows spatially identifying the exploitation potential of and the obstacles to RECs on an infra-urban scale, in order to promote them from an urbanistic point of view.

More precisely, we understand the obstacles as coinciding with the constraints on the establishment of RES plants, without which it is not possible to speak of energy communities, in accordance with the reference regulatory framework.

The potential is identified in urban areas where a maximization of the benefits attributed to RECs is expected. In this study, one of the main benefits associated with RECs is considered, which is the alleviation of energy poverty.

Since there is not a single conceptualization accepted in the scientific community of the subject, we need to specify how to spatially identify urban areas characterized by greater energy poverty.

This condition, according to the most recent viewpoint, is not quantifiable by a single metric, but it refers to a more or less extensive number of variables. The latter are calculable through various indicators, or proxy variables, capable of summarizing a non-measurably latent variable with reference to the diverse characteristics that define it [47,48]. Poor energy performance of housing, high energy costs, and low-income residents are widely considered to be the proxy variables that reflect the causal factors in the occurrence of energy poverty in the reference literature. In fact, they are the most typically examined factors when building composite indices of energy poverty [49–53].

In Italy, these causal factors are not easily mapped with detailed open geospatial layers, as the necessary data are not openly accessible for the entire territory at a local level but only for specific areas.

To evaluate the energy efficiency of residential buildings, it is particularly challenging to locate public data on Energy Performance Certificates (EPC). In fact, some Italian Regions, including Campania, have not yet communicated the data pertaining to their territories for the National Cadastre of Energy Performance Certificates, which was formed in accordance with the Ministerial Decree of 26 June 2015 [54].

The price of energy, if it comes from centralized non-renewable sources, is highly dependent on the economy, the national and international markets, and taxation.

The Italian ministry responsible for national economic policy provides information on per capita income, primarily on a municipal level, with the exception of the main cities. Nevertheless, the knowledge of the territorial distribution of the existing social or affordable housing can support the localization of low-income areas. By 'Affordable Housing' we mean those homes intended for families with an income that is too low to access housing under a free market but not so low as to benefit from social housing. This spatial knowledge is typically offered by municipal urban planning tools.

With reference to housing energy efficiency, multiple models can be referenced, despite the lack of available data that allows for direct measurement of consumption and, consequently, energy performance of buildings. However, the models for evaluating the latter at an urban scale can be traced back to two main approaches: the 'top-down' and the 'bottom-up' approaches, depending on whether the input data refers to a higher or lower spatial scale, respectively [55–58].

Top-down approaches are considered to be affected by a certain degree of uncertainty, deriving from the data disaggregation operation. In other words, they are indicated to provide a first reading of the data territorial distribution at an interurban scale, but they need to be integrated with methods that exploit more detailed information.

Bottom-up techniques, on the other hand, are more suited to the spatial level of analysis needed to support urban planning processes.

The integration of Geographic Information Systems (GIS) and Building Information Modeling (BIM) has received limited attention in the research about energy efficiency assessment at the urban scale. Some scholars have already highlighted its application advantages, in order to assist urban and territorial planning [59–61]. As better specified in the next paragraph, the authors of this paper have proposed a model to evaluate the energy performance of residential buildings based on this integration, in the context of bottom-up approaches [46].

Therefore, in order to evaluate energy poverty, the model mentioned above is used to estimate the housing energy efficiency, while the low-income areas are considered as the social and affordable housing districts. As regards the price of energy, since it generally does not have a significant variability on an intra-municipal scale, we choose not to consider this factor.

2.2. Methodological Path

The proposed methodological path consists in mapping the RECs' exploitation potential, building the Energy Poverty map ('Macrophase 1'), and the obstacles to their establishment, elaborating the Constraints map ('Macrophase 2'). Finally, from the intersection of the previous maps, the Priority Areas map is derived ('Macrophase 3'), identifying the areas where the Municipal Urban Plan must foster RECs as a priority (Figure 1).

In order to elaborate the maps defined above, it is necessary to collect a series of input geospatial data. They relate to different datasets, which are freely accessible for planners, such as the topographic database, generally provided to municipalities for planning purposes, and census data [62]. As described below, some graphical documents of the Municipal Urban Plan must also be acquired.

Macrophase 1 incorporates the model already proposed by the authors in the same research project for the estimation of housing energy efficiency, which is briefly summarized below.

It consists in the estimation of energy performance on a census basis, in terms of indoor heating and domestic hot water production. The evaluation is carried out by associating each section with typical buildings, representative of the entire section. This association can be made operationally in a GIS environment, as already tested by the authors in previous studies. More precisely, this is made possible first by evaluating the recurring building typology, deduced by calculating the number of floors and the ratio between the dispersing surface and the heated volume, S/V. With this information, the building is categorized based on some main types: single-family house, multi-family house, terraced house, and apartment block. Secondly, in order to group residential buildings for uniform construction and plant engineering procedures, a redistribution is carried out in six age groups with the aforementioned homogeneous characteristics.

Following a matrix that contains in columns and rows the data relating to the recurring typology of the buildings and the age group thus obtained, the typical building is identified and assigned to each census section. At this stage, with the help of BIM, it is possible to estimate the annual energy consumption, expressed in kWh/m^2, for each recognized building type, which is modeled by changing the input parameters according to the climate zone and the geologic, technological, and plant characteristics for the specific case under study. TerMus software (ACCA Software S.p.A., Bagnoli Irpino, Italy) is suggested to be used, as the calculation of energy consumption is made in accordance with the applicable Italian law, the Ministerial Decree of 26 June 2015. The latter requires the assessment of the *EPgl,nren* index, based on the building features. This index, calculated with BIM, is then spatialized for census tract in a GIS environment and reclassified into the ten values ranges set by the same decree, corresponding to ten energy performance classes [46].

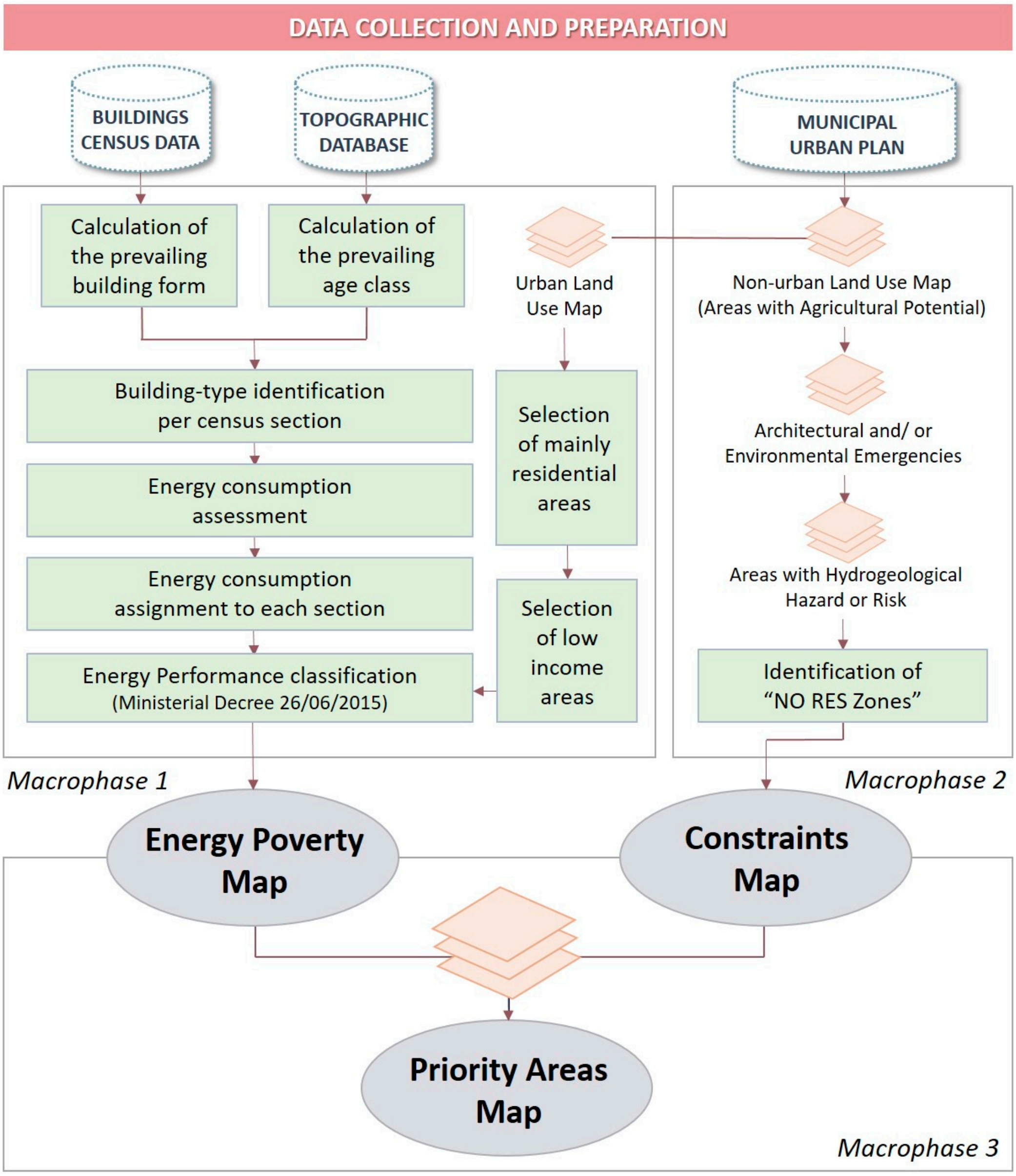

Figure 1. Workflow of the proposed methodology (Rearrangement from figure in [45]).

At this stage of Macrophase 1, from the urban land use map of the Municipal Urban Plan, it is possible to perform a selection of primarily residential areas. By intersecting the map of the areas mainly occupied by houses, thus obtained, with the map that represents the territorial distribution of the energy performance class per section, a new map is derived, where the class of each area for residential use is reported.

Thus, it is possible to draft the Energy Poverty map, excluding the best performing classes and highlighting the districts made up of existing social and/or affordable housing, which serve as a proxy for low-income urban areas.

In Macrophase 2, it is required to select the variables that, according to present legislation, constitute a barrier to the technical feasibility of RECs. To design a broad technique that is independent of specific region rules, the National Energy Service Manager’s recommendations are referenced [63]. More precisely, the selected constraint factors characterize, on the whole, the so-called “No RES Zones”, i.e., where it is not permitted to place plants powered by renewable energy sources: areas linked to the safeguarding of environmental resources and the protection of cultural and landscape heritage; areas linked to the protection of valuable agricultural crops; areas related to defense against natural hazards (Table 1).

Table 1. Type and description of areas unsuitable for the installation of RES plants.

Type	Description
Areas linked to the safeguarding of environmental resources and the protection of cultural and landscape heritage	The areas included in the Official List of Protected Natural Areas, such as those included within the perimeters of national, regional, and interregional parks, consisting of land, river, lake, or marine areas of national or international importance for their naturalistic values
	Wetlands characterized by highly biodiverse ecosystems, present in the list drawn up according to the Convention on Wetlands of International Importance (Ramsar Convention, Ramsar, Iran)
	The areas included in the Natura 2000 Network, which is made up of Sites of Community Importance (Directive 92/43/EEC) and Special Protection Areas (Directive 79/409/EEC), established to guarantee the maintenance of natural habitats and species of flora and fauna at risk
	The Important Bird Areas (IBA, London, UK), a name referring to areas that play a key role in the protection of birds and biodiversity, the identification of which is part of a worldwide project, managed by the non-governmental organization BirdLife International
	The areas that perform decisive functions for the conservation of biodiversity, for example: buffer zones or areas contiguous to protected natural areas; protected natural areas subject to proposal to the competent bodies but not yet included in the official lists; areas of ecological–functional connection and continuity between the various natural and semi-natural systems; areas of reproduction, feeding, and transit of protected fauna species; areas in which the presence of animal and plant species worthy of protection is ascertained according to international conventions (Conventions of Bern, Bonn, Paris, Washington, Barcelona)
	The sites included in the UNESCO world heritage list, as well as the buildings and the areas subject to declaration of significant cultural or public interest pursuant to the national legislation on cultural and landscape heritage
	The areas located near archaeological parks or areas and buildings identified as emergencies of particular cultural, historical or religious interest, as well as those that have international notoriety and are relevant for their tourist attractiveness
Areas linked to the protection of valuable agricultural crops	Agricultural areas affected by quality agri-food production, i.e., organic productions, productions with recognized denominations (DOP, IGP, STG, DOC, DOCG), traditional productions, productions of particular value for the landscape and cultural context in which they are found
Areas related to defense against natural hazards	The areas characterized by hydrogeological hazard, bounded in the Hydrogeological Stability Plans (PAI), adopted by the competent Basin Authorities

The maps created in the regular municipal planning process serve as the data source for the geographical localization of the aforementioned constraints. More precisely, these graphic documents are the following, respectively:

- Architectural and/or environmental emergencies maps, in which the planners highlight the elements of the municipal territory that bear cultural, environmental, and naturalistic value and therefore deserve protection;
- Non-urban land use maps, generally drawn up by agronomists, in order to detail the agricultural or natural land use;
- Areas with hydrogeological hazard or risk, which, barring more detailed studies conducted by geologists during the plan drafting, planners assume from the documents of Hydrogeological Stability Plans (PAI), adopted by the competent Basin Authorities.

The aforementioned maps are part of the minimum documents that form a Municipal Urban Plan, according to current Italian legislation.

In Macrophase 3, the "No RES zones" map has to be produced in order to identify the whole set of obstacles to the RECs formation on the municipal territory. This is made feasible by enveloping all the areas identified in the Constraints map, through a geoprocessing operation carried out in a GIS environment.

The final Priority Areas map is built through an overlay mapping between the "No RES zones" map and the previously elaborated Energy Poverty map.

The priority areas are obtained by selecting only the urban areas characterized by the worst energy performance, identified in the last three classes: E, F, and G.

Among all the low-income urban areas, only those falling into the aforementioned classes must be identified in order to spatially locate the most critical urban areas both from a social and energetic point of view.

Through the urban areas thus identified, public decision makers can subsequently assess whether it is appropriate to identify further priority classes, for example, by giving higher priority to low-income areas that fall into the aforementioned groupings.

3. Case of Study

The methodology presented in this paper is applied to the case study of the territory of Pagani (SA), in the Campania Region (Italy). This experimentation is part of the studies and research conducted by the authors, in favor of local authorities for the formation of the Municipal Urban Plan (PUC), in accordance with the current regional legislation [64].

After 37 years, the municipality is updating its existing urban planning tool, represented by a General Town Plan approved in 1985, with the integration of the studies carried out by our research group, in force due to a recent official convention.

This circumstance allowed easier access to the input data necessary for the implementation of the proposed model, as well as direct control of the same, managed and processed during the activities envisaged by the aforementioned agreement, which can be consulted on the dedicated website [65].

In particular, the input data are included in the documents that constitute the Preliminary of the Municipal Urban Plan (PUC Preliminary), which can be freely viewed on the aforementioned website, where they are organized into the following sections: "A-Territorial analysis", "B-Geomorphological analysis", "C-Agronomic analysis", "D-Urban Planning Analysis" [66].

Beyond the operational convenience, Pagani is an optimal case study to effectively test the proposed model. In fact, it is located in a vast conurbated area called "Agro-Nocerino-Sarnese" (Figure 2A,B), which has a total of 300,000 inhabitants and a high density, both a building density and a residential one, particularly high in the municipality in question.

Figure 2. The study case of Pagani Municipality in Campania Region (**A**), within the Agro Nocerino-Sarnese vast area (**B**), and the spatialization of census tracts for the municipal territory (**C**).

The territory of Pagani has a predominantly flat surface, with a maximum altitude of 855 m, to the south, and a minimum altitude of 15 m, to the north, falling into the climatic zone C (1184 degrees day). It is well served by the primary road network, as it is crossed by a motorway (E45) and state (SS18) axis, as well as being next to another motorway axis (A30).

From the census data, relating to the 125 total tracts (Figure 2C), it emerges that over half of the total building stock was built before the 1990s. The highest number of buildings built was reached in the decade 1970–1980.

In addition, the Municipality of Pagani is classified as the 44th municipality of the Campania Region for housing disadvantage, out of a total of 550 municipalities.

To the south, part of the foothill territory is included in the Parco dei Monti Lattari and within the perimeter of the Territorial Urban Plan of the Sorrentino–Amalfi Area, two territorial planning tools aimed at protecting the rich environmental and landscape resources that characterize the Amalfi and Sorrentina coasts, between the provinces of Salerno and Naples. The protected area, almost completely free from construction, is followed by the dense urban center, proceeding northwards. The urban center has developed around the historic center, which is mainly well-preserved in "subzone I", representing a valuable cultural resource. Part of the historic center, identified with the term "subzone II", is instead occupied by recent buildings of poor value, built in place of historic buildings. Some peripheral areas of the historic center, in correspondence with "subzone III", are particularly degraded, with buildings in precarious static conditions. Proceeding further north, there is the agricultural territory, characterized by a high diffusion of low-density settlements. In fact, the city's economy is mainly supported by agricultural activities related to the production of fruit and vegetables, to which the other production sectors are linked, with particular reference to the canning and packaging industries (Figure 3).

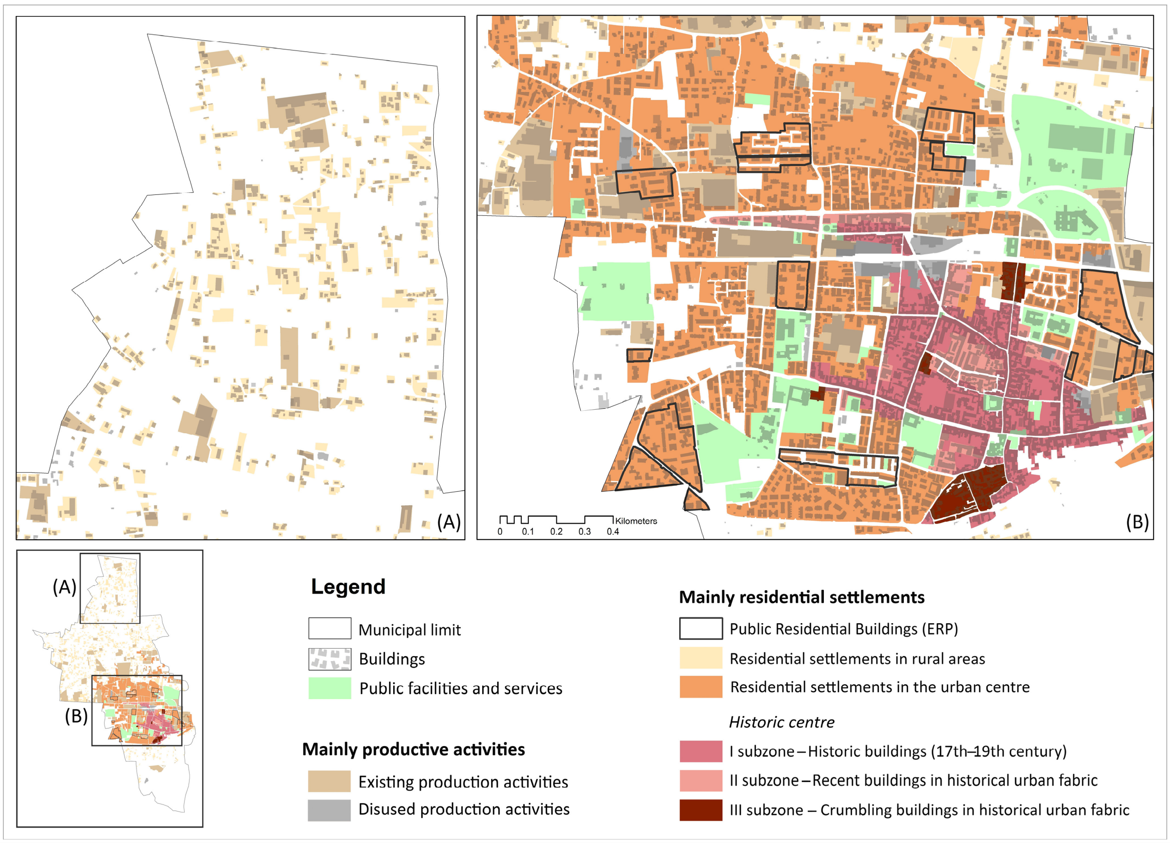

Figure 3. Details of the land use for the scattered settlements of rural areas (**A**) and for the urban center (**B**). Authors' elaboration on the "Urban land use Map", a graphical document of the PUC Preliminary [66].

4. Results

The input data collected for the territory in question were processed in a GIS environment, using the commercial software ArcGis (Esri, Redlands, California, U.S.). The Energy Poverty map was obtained starting from the map representative of energy efficiency spatialization on a census basis. The latter was crossed with the urban land use one, drawn up among the PUC Preliminary documents, extrapolating only the themes referring to mainly residential areas. At this stage, the districts made up of social housing (ERP) have been highlighted, in order to detect low-income urban areas (Figure 4). In the case of Pagani, ERP was implemented in accordance with the rules of the pre-existing General Town Plan, while there are no existing affordable housing areas, which are only provided by the urban planning tool currently under development. The acquired results demonstrate little variation in the classes specified in relation to existing regulations: only the last four classes are detected. However, this outcome was expected, considering the age of the municipal building stock of Pagani. Furthermore, this result is in line with the Italian trend [54]. However, from the results, it is evident that the rural areas of settlement dispersion have worse energy classes than the more central areas.

Later, the Constraints map, representative of the obstacles to the implementation of RES plants, was built, starting from the data obtained from the PUC Preliminary documents (Figure 5). This map shows how the constraints are located mostly in the mountainous area, seat of the “Monti Lattari” Regional Park and the Natura 2000 Network, as well as partially governed by the Territorial Urban Plan of the Sorrentino–Amalfi peninsula. Other constraints are in the ancient center, rich in important material testimonies. It should be noted that only “I Subzone” was considered for identifying the “No RES zones”, not the entire historic center. The latter is divided into three sub-areas in the PDP, but only the first area has the requirements set out in the guidelines for the identification of constraining factors in the installation of RES plants. In fact, the remaining subzones have lost their historical–architectural value, due to incongruous interventions carried out over time. Further constraints are in rural areas, extensively characterized by quality agro-food productions, on which the local economy is based. The extended protected areas are accompanied by the rural landscape of the lowland territories, and the orchards and minor fruits represent the largest agricultural presence, covering 44% of the Pagani municipal territory. The latter is widely affected by hydrogeological hazard and/or risk: from the analysis of the current hydrogeological stability plan (PAI), it emerges that the foothills area is particularly sensitive to landslide dynamics, while the territory north of the urban settlement, crossed by the hydrographic network of the “Comune” Alveo, is distressed by hydraulic hazard and risk.

It can be seen that the territorial extension of the constraints that occupy the municipal area is significant. This is common to many municipalities of the Italian territory, entirely motivated by environmental, cultural and landscape resources worthy of protection.

Finally, the Priority Areas map was obtained (Figure 6), i.e., those neighborhoods or districts most critical in terms of buildings’ energy efficiency and the income of residents. Instead, these areas are suitable for the installation of RES plants, as they do not belong to the “No RES zones”, located by enveloping all the areas identified in the Constraints map. It can be noted that the low-income neighborhoods with priority for intervention are few compared to the total of ERP neighborhoods, since many of them are burdened by constraint conditions, mostly determined by the presence of hydraulic risk.

From the analysis of the final priority areas map thus obtained, the most critical areas correspond broadly to the neighborhoods located in the urban center, but their presence is also found in residential areas of the agricultural sector, even if to a lesser extent (Figure 7). However, in Italy, it is well known that population density decreases significantly when moving from the center to rural areas. Furthermore, the settlement fabric differs in terms of building types and the relationship between buildings and open spaces. In the case of Pagani, in the center, there are areas for public services, almost absent in rural areas, which have scattered productive activities. Both types of areas could play an important role in conducting the process of setting up RECs, on the one hand by the public hand, on the other by private initiative, i.e., by entrepreneurs, adequately incentivized through reward mechanisms to be foreseen in the PUC.

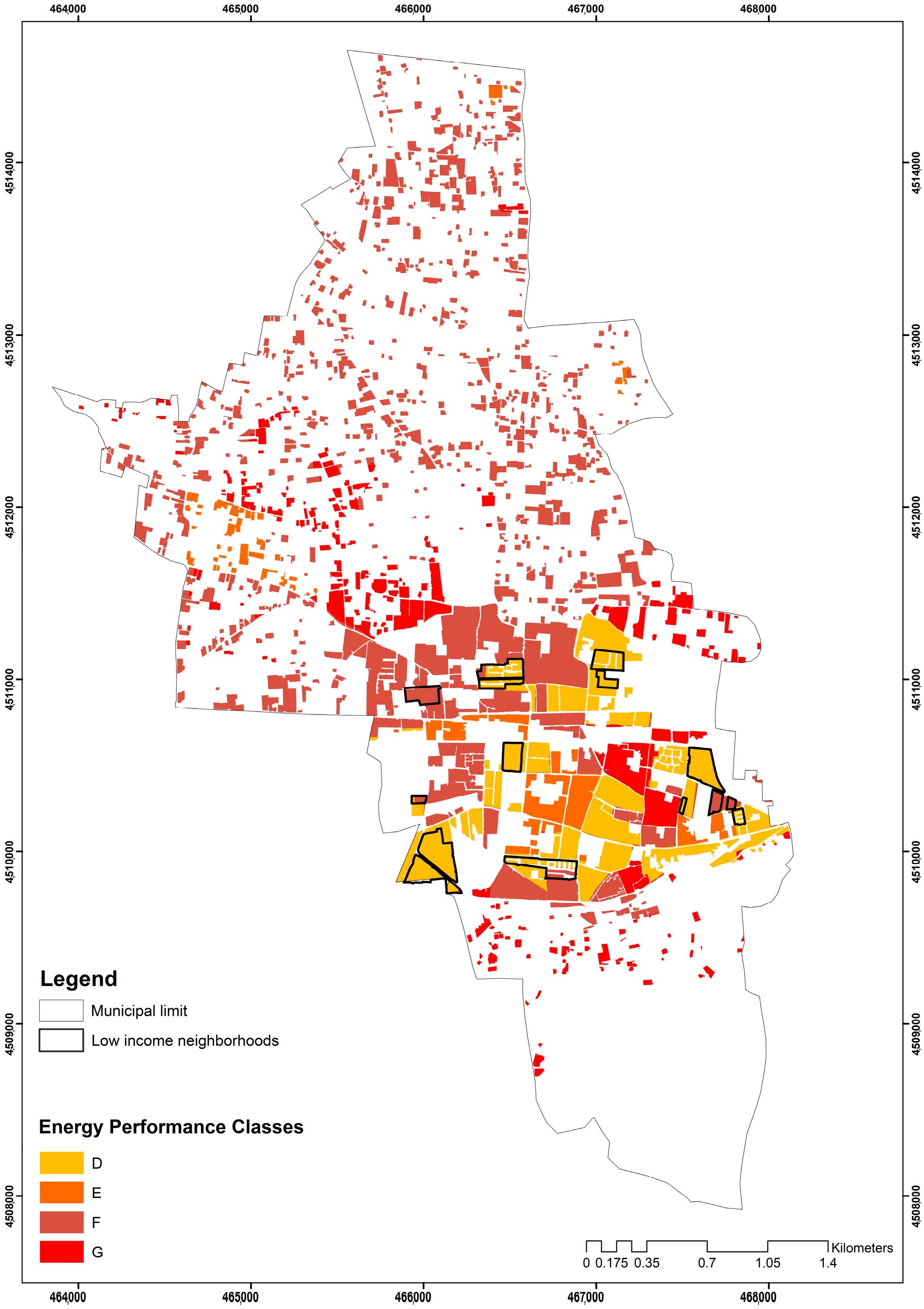

Figure 4. Energy Poverty map.

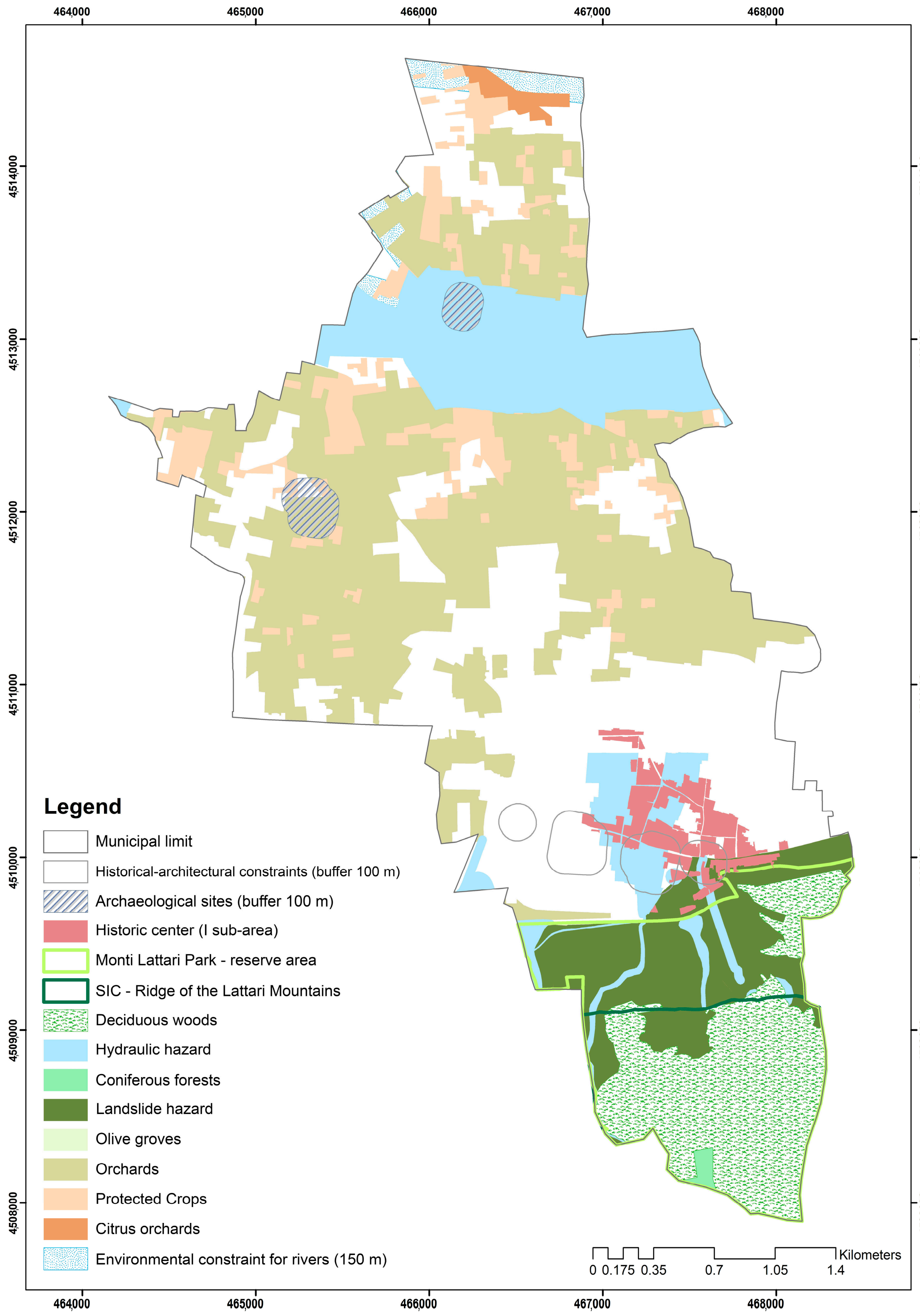

Figure 5. Constraints map.

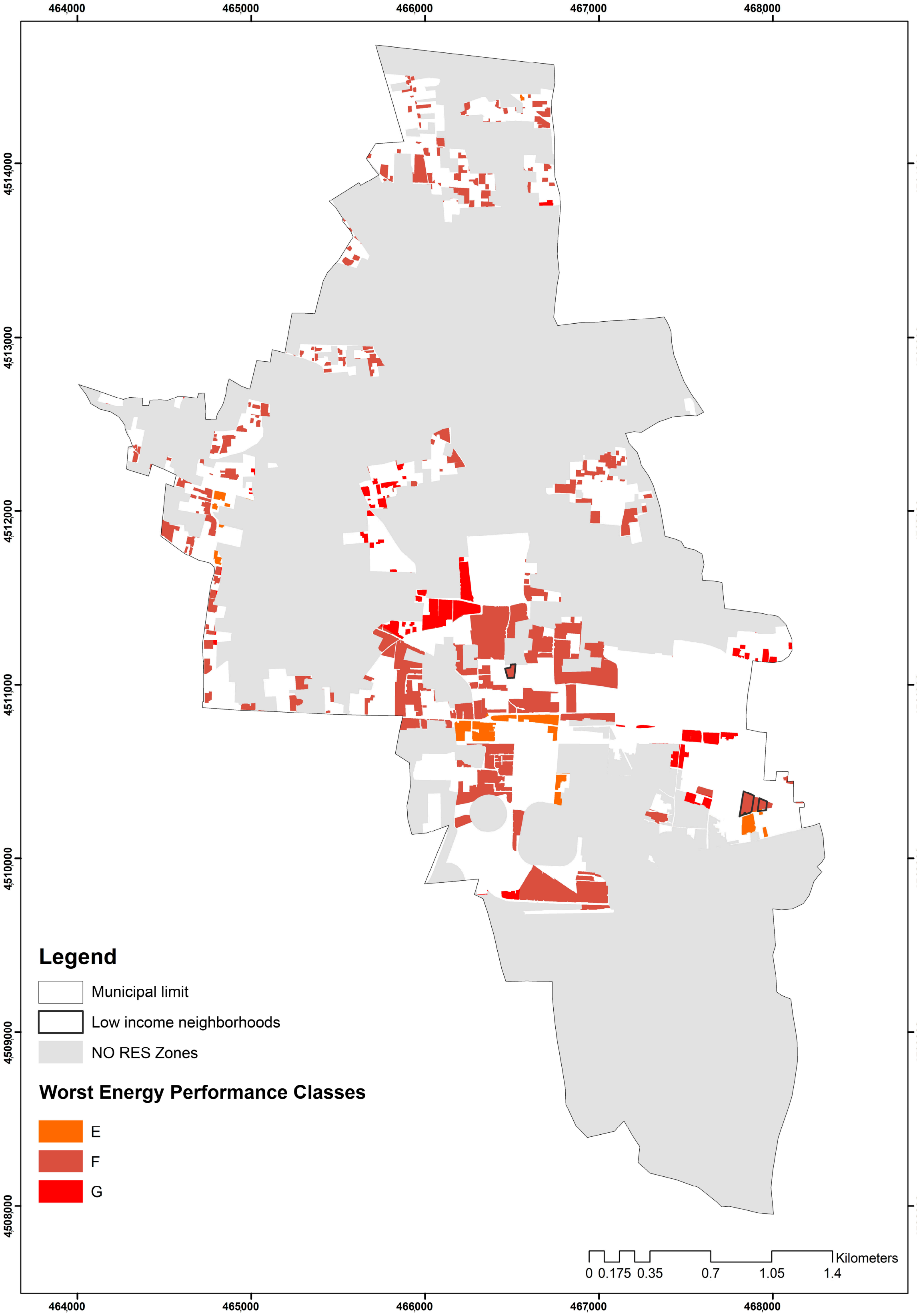

Figure 6. Priority Areas map.

Figure 7. Priority Areas map. Details on the city center (**A**,**B**) and on scattered rural settlements (**C**,**D**).

5. Discussion

The priority areas, delimited in the specific map obtained by applying the model presented, are identified in order to minimize obstacles to RECs' establishment and maximize their benefits.

The criterion followed for the selection of intervention areas constitutes a first innovation with respect to previous studies on the subject, referred to in the Introduction section (see Section 1.2). Among the cited works, the criterion for choosing the urban areas under study, when specified, is the presence of pre-existing renewable energy plants. In fact, this circumstance allows minimizing the investment costs necessary to equip potential energy communities with the technological infrastructures necessary for their operation [31]. In addition, the pre-existence of local energy resources favors the social acceptance of the RES installation and the predisposition of citizens to join energy communities [29]. This approach, although acceptable, poses the risk of intervening where it is not a priority, accentuating the internal imbalances of the city.

The importance attributed to the issue of energy poverty is a further novelty of this work. In the previous studies analyzed, energy poverty is not considered in the search for optimal REC configurations, although it is recognized as one of the main benefits brought by the communities themselves and relevant in the current global scenario.

In the absence of shared methods and techniques for its measurement, energy poverty is mapped with reference to the main drivers that determine it according to the literature on the subject, including the income situation and the energy efficiency of residential buildings. The latter is evaluated on an urban scale according to a method based on BIM–GIS integration, proposed by the authors in a previous scientific contribution preparatory to this work [46]. Thanks to this method, the energy consumption obtained for census tract is indicative of the real local value, since the input data necessary for the calculation of consumption are entered on the basis of the specificities of the buildings in the territory under study. This aspect is essential for the reliability of the methodological proposal presented here, in order to ensure its transferability to other case studies.

In light of this, compared to the preliminary proposal by the same authors [45], in which the use of consumption data from the literature is also suggested, the modeling of the district representative building type in a BIM environment is deemed necessary. In fact, the more realistic the results shown in the proposed map are, the more objective the choice of areas in which to intervene as a priority will be.

Furthermore, the proposed methodology allows to promote the RECs in the Municipal Urban Plan. Otherwise, the current plan may be an obstacle to their development, as it is not updated with respect to the issue of RECs [29,33].

In this vein, the involvement of citizens in the participatory process that accompanies the plan formation can be a further way to inform and raise awareness of potential REC users, promoting their further development [67,68].

It is also crucial that the Municipal General Plan is consistent with the objectives and actions of the Sustainable Energy and Climate Action Plan, where this last instrument is expected, in order to encourage greater coordination of urban plans aimed at pursuing the energy transition. This could be hindered by the asynchronicity in the drafting of these tools, as well as by the excessively sectoral nature of the SECAP, as already highlighted by some scholars [31,43]. In this sense, the relevance of the Municipal Urban Plan in promoting renewable energy communities is better understood, since it is a general and non-sectoral tool.

Another novelty of the study concerns its implications for the definition of REC promotion strategies, supported by public investments. In fact, local authorities are more likely to be successful in obtaining financing, since the target areas are identified on the basis of an analytical study, aimed at directing the actions where their greater effectiveness is expected. This result is considerable in light of the economic incentives that the government has implemented with the PNRR in order to accelerate the post-pandemic recovery.

6. Conclusions

In a global context in which it is necessary to significantly reduce climate-altering emissions and the cost of energy, renewable energy communities represent an important tool to facilitate the transition to carbon neutrality and reduce energy poverty. Although RECs have received little attention in urban planning, the latter can play an important role in their incentivization. This is particularly true in Italy, where the complexity of the planning system, generally not updated on the subject, can make the authorization process for RECs difficult and slow down their rapid spread.

This work proposes a methodology that allows supporting municipal urban planning in promoting RECs' establishment, spatially identifying obstacles and their development potential at an infra-urban scale. The obstacles are understood as the constraints on the installation of RES plants, while the potential is identified in urban areas where a maximization of the benefits brought by RECs is expected, with specific reference to the lowering of energy poverty. The areas with the greatest potential that are at the same time not affected by obstacles are considered a priority for the promotion of RECs through urban planning.

The results of the application to the case study show how priority areas can be found both in the urban center and in the agricultural territory of the settlement dispersion. Since these are very different settlement fabrics in terms of land use, population density, and buildings, this result leads us to believe that the optimal REC configurations can vary from the most central urban areas to the most rural ones. This variation is understood in terms of the number of users/buildings to be clustered, the spaces available for the installation of RES plants, and potential leaders who can lead the community development process.

Future research could concern the application of the proposed methodology to territorial contexts different from the one examined. This is possible because the necessary input data are normally available to urban planners. In this vein, the application of the proposed model could be interest to municipalities falling in the so-called "inland areas", where energy self-sufficiency through REC could be a lever for combating demographic desertification [69–71].

Furthermore, the methodology shown here may be adjusted in the future by exploring additional issues that have not yet been considered. For example, the cognitive framework, thus constructed to support the planning process, can be integrated with maps useful for understanding the characteristics of the electrification present in the municipal area, i.e., networks served by the primary substations and the secondary medium- and low-voltage substations, in agreement with the indications of the current Italian legislation on energy communities. This would make it possible to identify the minimum perimeters of RECs. However, finding such data is not a simple operation, since it requires the direct involvement of local managers. This operation could be facilitated by building a network of potential *stakeholders*, who examine the territories from time to time, in the process of setting up an energy community [72,73]. Local managers, together with coalitions of citizens and local authorities, are indeed privileged interlocutors in this sense [74], especially in light of the technical limitations imposed by the legislation in force, which favors the sharing of the energy produced and not used through the existing distribution grid.

Finally, it seems appropriate to specify that the possibility of concretely implementing REC in the priority areas, identified also in light of the current electrification system, depends on the technical, energy, and economic feasibility of the projects, which requires the contribution of multiple knowledge and disciplinary skills. In fact, with the support of experts from different disciplines, the ultimate goal of the research work in progress is to identify potential REC-type configurations, which are particularly efficient on an infra-urban scale. This result would allow the drafting of guidelines and recommendations for urban planning, with reference to the Municipal General Plans and the Action Plans for Sustainable Energy and Climate, in order to prefigure a land use such as to encourage the development of REC, with a view to ensuring a sustainable energy transition.

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