A Model to Detect Low Income Urban Areas to Plan Renewable Energy Communities Against Energy Poverty

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Abstract. This work is included in a broader research project, aimed at promoting the development of Renewable Energy Communities (RECs) through urban planning in priority areas for intervention. According to a methodology already proposed by the author, priority areas, mapped on an infra-urban scale, are intended to be located where a minimization of the constraints and a maximization of the benefits deriving from the RECs establishment are expected, with particular reference to the reduction of energy poverty. The aim of this work is to detail the already proposed methodology, in order to better assess energy poverty. To this end, a model for the construction of a composite index of urban poverty is proposed, starting from basic indicators, selected following a review of the technical-scientific literature on urban poverty and deprivation or distress. The spatialisation of the obtained index makes it possible to obtain a more detailed map of energy poverty with respect to the previously proposed methodology. The model is applied to the case study of Pagani, in Campania Region (Italy), which is the study area investigated in the article that precedes this work, which allows to compare the results already obtained and appreciate the progress made by the model presented in this paper.

Keywords: Urban and Energy Poverty · Renewable Energy Communities · Urban Planning

1 Introduction

The goal of carbon neutrality, promoted by the European Green Deal by 2050, has been made legally binding by the recent European climate legislation, which introduces the ambitious goal of reducing net greenhouse gas emissions by at least 55% by 2030, compared to the levels of 1990 [1].

At the same time, in Europe the phenomenon of energy poverty is increasing significantly [2], to the point that the issue of the 'expensive bill' is constantly on the news. Due to the Russia-Ukraine war crisis, which has led to turbulence in energy markets, price volatility and global energy insecurity, the phenomenon of energy poverty no longer affects only low-income families, "but also those with lower-middle income and potentially others in some Member States as well" [3], threatening the achievement of the ambitious European decarbonisation targets.

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Renewable Energy Communities (RECs) arouse growing interest for the fight against energy poverty and, in general, for the contribution of numerous environmental benefits, including: the energy efficiency of existing buildings; the promotion of the use of energy from renewable sources and the social acceptance of the latter; the reduction of climate-changing emissions [4–6].

According the European Directive "RED II", RECs are coalitions of citizens, small-medium enterprises and local authorities, including municipal administrations, which are able to produce, consume and exchange energy produced from renewable sources, with the main purpose of providing environmental, economic or social benefits to the community itself or to the local areas in which it operates [7]. The link with the local areas in which they are established makes the RECs a relevant tool for urban planning, in order to protect vulnerable people from the current price increase and ensure a just transition of cities towards climate neutrality.

This work is included in a broader research project, aimed at promoting the RECs development through urban planning. As part of the project, a methodology to identify priority areas in which to address this action was proposed, according to a place-based approach, as published in a previous study [8].

Priority areas, mapped on an infra-urban scale, are located where a minimization of the constraints and a maximization of the benefits deriving from the RECs establishment are expected. Constraints are defined as all factors for which an urban or rural area is not suitable for the installation of RES plants. Among the benefits provided by RECs, particular reference was made to reducing energy poverty, as this topic is little explored in the identification of RECs potential spatial configurations in the relevant literature.

In the absence of an agreement in the international scientific community on the methods and techniques for measuring energy poverty, it is evaluated with reference to two main proxy variables: the energy performance of residential buildings and the low income of residents. As no open data is available at the chosen spatial level, these variables are in turn estimated with specific methodologies. However, the second variable was evaluated expeditiously by associating public (ERP) and social (ERS) housing neighborhoods with low-income areas.

The aim and the novelty of this work compared to the previous work is to detail the already proposed methodology, with particular reference to the assessment of low income urban areas, since an increasing number of families are at risk of energy poverty, not only those residing in ERP and ERS neighborhoods. To this end, a model for the construction of a composite index of urban poverty is proposed. The index is constructed starting from basic indicators, selected following a review of the technical-scientific literature on the topic of poverty, deprivation or distress affecting urban areas.

The model is applied to the case study of Pagani, in Campania Region (Italy), in the context of studies and research conducted for the formation of the Municipal Urban Plan, by virtue of an institutional agreement between the Municipality and the Department of Civil Engineering (DiCiv) of the University of Salerno[1]. In addition, Pagani is the

[1] This study is developed within the research project "Agreement between DiCiv and municipality of Pagani for studies and research to support the formation of the Municipal Urban Plan". Prof. Roberto Gerundo is the project scientific responsible, while Alessandra Marra is principal investigator and technical coordinator of the research group.

study area investigated in the article that precedes this work, which makes it possible to compare the results already obtained and appreciate the progress made by the model presented here.

To this end, the following Sect. 2 describes the proposed methodology, applied to the case study described in Sect. 3. The results of this application are presented and discussed in Sect. 4, while Sect. 5 reports the main conclusions of the study and future developments of the research.

2 Materials and Methods

2.1 Selection of Basic Indicators

In the Italian geographical context, the territorial variation of per capita income is not known at the intra-city or neighborhood detail. In fact, the Ministry of Economy and Finance provides this data with reference to a lower spatial level, i.e. for each Italian municipality, with the exception of some large cities.

However, to overcome this problem, it is possible to consider other variables, measurable at the local level, considered to be expressive of a potential socio-economic hardship of resident families, according to the technical-scientific literature on urban poverty. These proxy variables have been traced in order to identify measures other than income, since incomes tend to fluctuate over time. Moreover, it is likely to run into problems of under-reporting, especially with reference to income derived from private entities [9]. The literature relating to the phenomenon of urban deprivation or distress also offers criteria and indicators useful for identifying urban areas or neighborhoods characterized by urban poverty [10–12].

The economic value of the house is notoriously considered a proxy variable for estimating the income of its inhabitants. In Italy, the real estate prices can be deduced by consulting the data from the Observatory of the Real Estate Market (OMI), thanks to which the Revenue Agency has mapped urban and rural areas of different market value for the whole Italian territory [13]. However, the level of spatial detail does not offer differentiation within urban fabric, i.e. on an infra-urban scale.

According to a technical report drawn up for the Italian metropolitan cities, there are three indicators that are best able to estimate the income vulnerability of families in Italy: low schooling rate, active employment rate, discouraged unemployment rate [14]. The same report also suggests further indicators, specifying that the choice must be made with reference to the urban system under study. For example, the ratio of rented houses to total dwellings is an appropriate indicator, as it is a typical feature of areas where urban poor are spatially concentrated.

The indicators proposed in the aforementioned report can be measured through simple algebraic operations starting from the census variables, the data of which are periodically released by the National Institute of Statistics for each census zone of the Italian territory, i.e. on an infra-urban scale, therefore they are considered suitable and selected in this study (Table 1). Overall, these indicators can be traced back to several domains or dimensions of urban poverty: Employment; Education and Culture; Demographic Structure; Building quality; Property deed.

Table 1. Selected indicators, with their definition and domain of reference.

Domain	Indicator	Definition
Employment	I_1 - Active unemployment rate	Ratio between the unemployed population looking for new employment and the population belonging to the total labor force
	I_2 - Unemployment rate discouraged	Ratio of people not in the labor force, i.e. those not classified as employed or seeking work, to the population in the total labor force
Education and Culture	I_3 – Low schooling rate	Ratio between the population with an educational qualification equal to or less than a lower secondary school diploma (middle school) on the total resident population aged 6 and over
Demographic Structure	I_4- Old age index	Ratio of the population of 65 years of age and older and the population of age 0–14 years
	I_5 - Incidence of large families	Ratio between the number of families with 6 or more members and the total number of families
	I_6 – Vulnerable migration rate	Ratio of foreigners from low-income countries to total resident population
Building quality	I_7 – Building degradation index	Ratio between residential buildings in poor and mediocre state of conservation and total residential buildings
Property deed	I_8 – Rate for rental housing	Ratio of rented occupied dwellings to total occupied dwellings

2.2 Construction of the Urban Poverty Index

The construction of the composite index is carried out by first normalizing the m basic indicators (I_{m}, with $m = 1, \ldots, 8$) using the "Min-Max" method. Among the possible normalization techniques, this procedure makes it possible to relate the unique values of a single input indicator ($x_{m,i}$) to the maximum ($x_{m,i_{max}}$) and minimum ($x_{m,i_{min}}$) value that the indicator itself assumes in the territory under study, consisting of n census sections (with $\mathrm{i} = 1, \ldots, \mathrm{n}$). In the chosen set all the indicators have positive polarity, i.e. an increase in their value corresponds to an increase in criticality in the corresponding domain. Thus, the linear correlation formula that yields the respective normalized values ($y_{m,i}$) can be written as follows:

$$y_{m,i} = \begin{cases} 0 & x_{m,i} \leq x_{m,i_{min}} \\ \frac{x_{m,i} - x_{m,i_{min}}}{x_{m,i_{max}} - x_{m,i_{min}}} & x_{m,i_{min}} < x_{m,i} < x_{m,i_{max}} \\ 1 & x_{m,i} \geq x_{m,i_{max}} \end{cases}$$

The domain of each normalized indicator consists of the interval [0, 1], where 1 corresponds to the maximum degree of criticality, while 0 represents the minimum.

The composite index of urban poverty for each section (UPI_i) is obtained expeditiously through a weighted average of the normalized indicators, each of which is assigned a weight (w_m):

$$UPI_i = \frac{\sum_m w_m y_{\mathrm{m,i}}}{\sum_m w_m}$$

If the indicators are not linearly correlated to each other, it is possible to adopt equal weights, so that the denominator of the previous formula will be equal to the total number of uncorrelated indicators. One of the suitable methods to investigate the possible existing linear correlation is to calculate the Pearson index. The correlation analysis must be carried out upstream of the normalisation, thus avoiding incurring any distorting effects caused by this operation. This type of analysis also makes it possible to reduce the number of basic indicators selected to that represented by the uncorrelated variables [15, 16].

In order to identify different levels of urban poverty, the classification is carried out on the basis of the Natural Break method, which is also suitable for any non-uniform data distributions [17]. Given the number of classes, for example equal to five (Very Low, Low, Medium, High, Very High), this method allows to maximize the variance between the classes and minimize the variance within each class.

3 Case of Study

The city of Pagani is part of a dense intermunicipal conurbation, called 'Agro-Nocerino-Sarnese', located in the Salerno Province of Campania Region (Italy). Pagani is characterized by a high population density, concentrated in an urban continuum that connects to the metropolitan area of Naples, to the east, and to the urban pole of Salerno, to the west. This vast settlement area is characterized by a high degree of urbanization, which has led to a serious fragmentation of the rural landscape (Fig. 1).

With Executive Decree n. 17 of 4 March 2020, Campania Region updated the summary index of housing deprivation in the regional territory. This index, elaborated on a municipal basis, aggregates the municipalities into four different ranges, corresponding to the following classes: High, Medium-High, Medium-Low and Low. The synthetic index was constructed starting from the following indicators: the ratio between occupied dwellings and total dwellings, variable that takes the name of 'Housing Intensity Index'; the reciprocal of the ratio between the inhabited municipal area and the resident municipal population, a variable called 'Index of pressure on the housing stock'. As a result, the Municipality of Pagani is one of those with high housing deprivation, ranking as the 44th one out of a total of 550 Campania Region municipalities. Within the urban fabric, there are various districts of Public Residential Building (Fig. 2), implemented under the current General Regulatory Plan (PRG). The new Municipal Urban Plan (PUC), which will update the PRG, is formally approved in the preliminary component for now (PUC Preliminary), while the definitive project is being finalized.

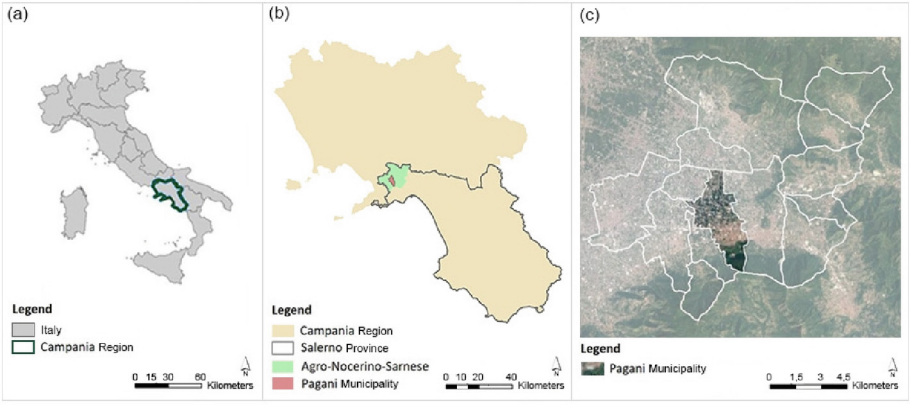

Fig. 1. Campania Region in the South of Italy (a) and the study area in the Salerno Province of Campania Region (b), with the Pagani municipal territory highlighted among all the Agro-Nocerino-Sarnese municipalities (c).

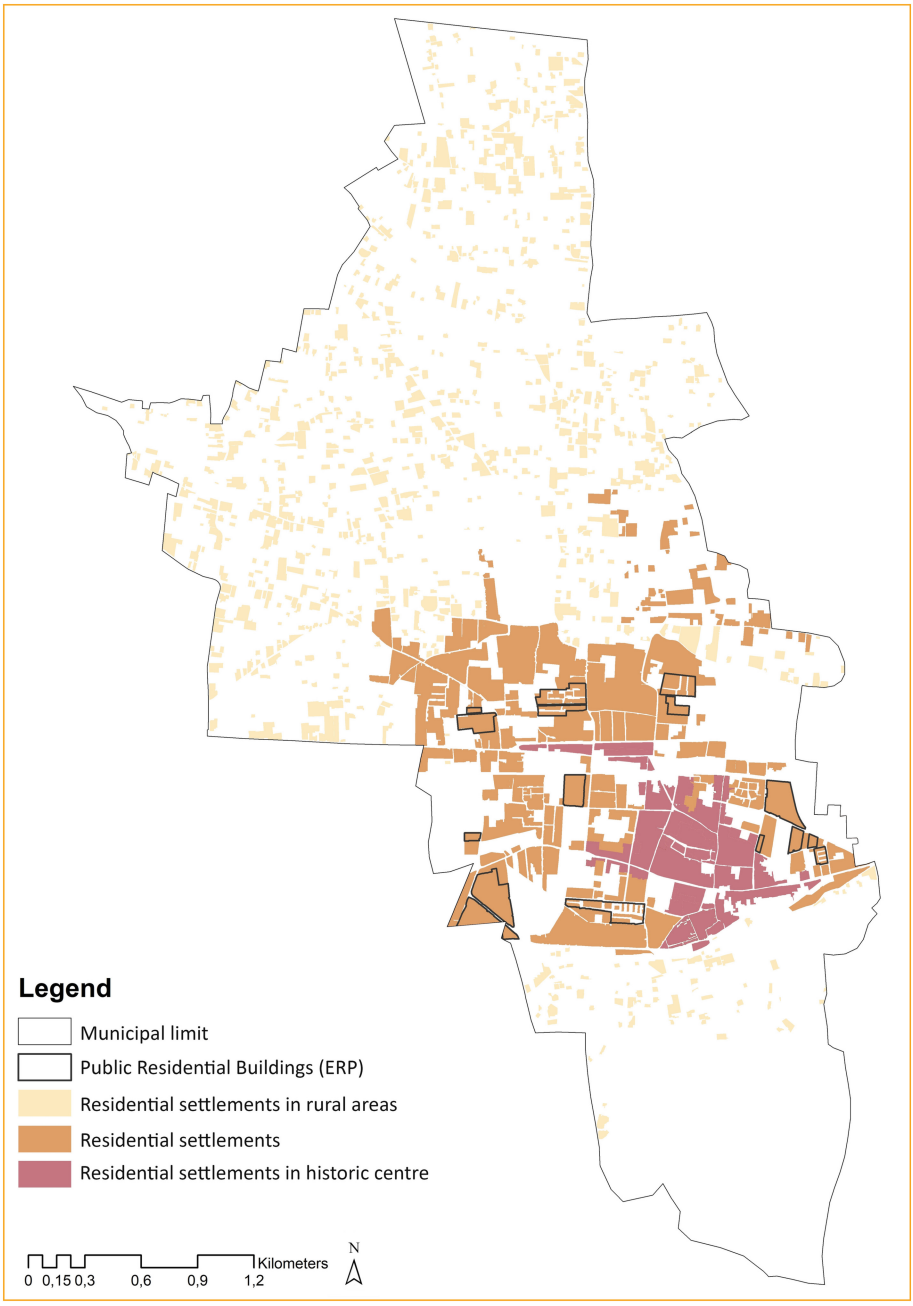

Fig. 2. Residential land use of Pagani Municipality. Author's elaboration on the Urban Land Use Map of PUC Preliminary.

4 Results and Discussion

The proposed methodology is applied to the case study, starting from the acquisition and preparation of the data needed to measure the basic indicators. As mentioned, data is available on a census basis for the entire national territory, but only those referring to each section belonging to Pagani Municipality were extrapolated. Since open data is not available at a more detailed spatial level, the census tract is identified as the minimum territorial unit for thematic mapping.

In a GIS environment, by building a *geodatabase*, in which the values of the input indicators are associated with the spatial polygons representing each section, it is possible to implement the formulations contained in the methodological proposal for the construction of the UPI index.

For the study area, all the proposed indicators merged into the composite index aggregation procedure, as Pearson's correlation analysis revealed little correlation between the selected variables. In fact, the values of Pearson's *r coefficient* are in the range 0.00008–0.134.

In this way, once the index values are known for each minimum spatial unit and by performing a classification with the Natural Breaks method in five intervals, the representative map of the territorial variation of socio-economic hardship in the territory in question is obtained. More precisely, the value of the composite index varies from a minimum of 0.075 to a maximum of 0.56.

This map is subsequently intersected with the urban land use map, with specific reference to the areas with a predominantly residential function, to which the input data refer (Fig. 3).

The final map shows that the composite index reaches its highest levels not only in areas traditionally considered low-income, i.e. public housing districts. Numerous other neighborhoods are affected by conditions of potential socio-economic hardship, both in the more central areas and in the rural areas of settlement sprawl.

The ERP districts, affected by a high and very-high index, are confirmed as urban areas representative of an income vulnerability of the residents, therefore their location is a valid criterion for the territorialisation of the phenomenon. However, the case in question demonstrates how they are not sufficient to capture the areas susceptible to potential socio-economic hardship in their entirety. A more detailed knowledge of the territorial distribution of this phenomenon is useful for more accurately mapping urban areas at risk of energy poverty. It follows a different and more precise spatial distribution of the priority areas for the promotion of RECs, compared with the priority areas map achieved in in the previous study that this work intends to integrate (Gerundo & Marra 2022). So, it is possible to use the simplified method when drawing up the preliminary plan, while the more detailed method is suitable for the definition of the final plan.

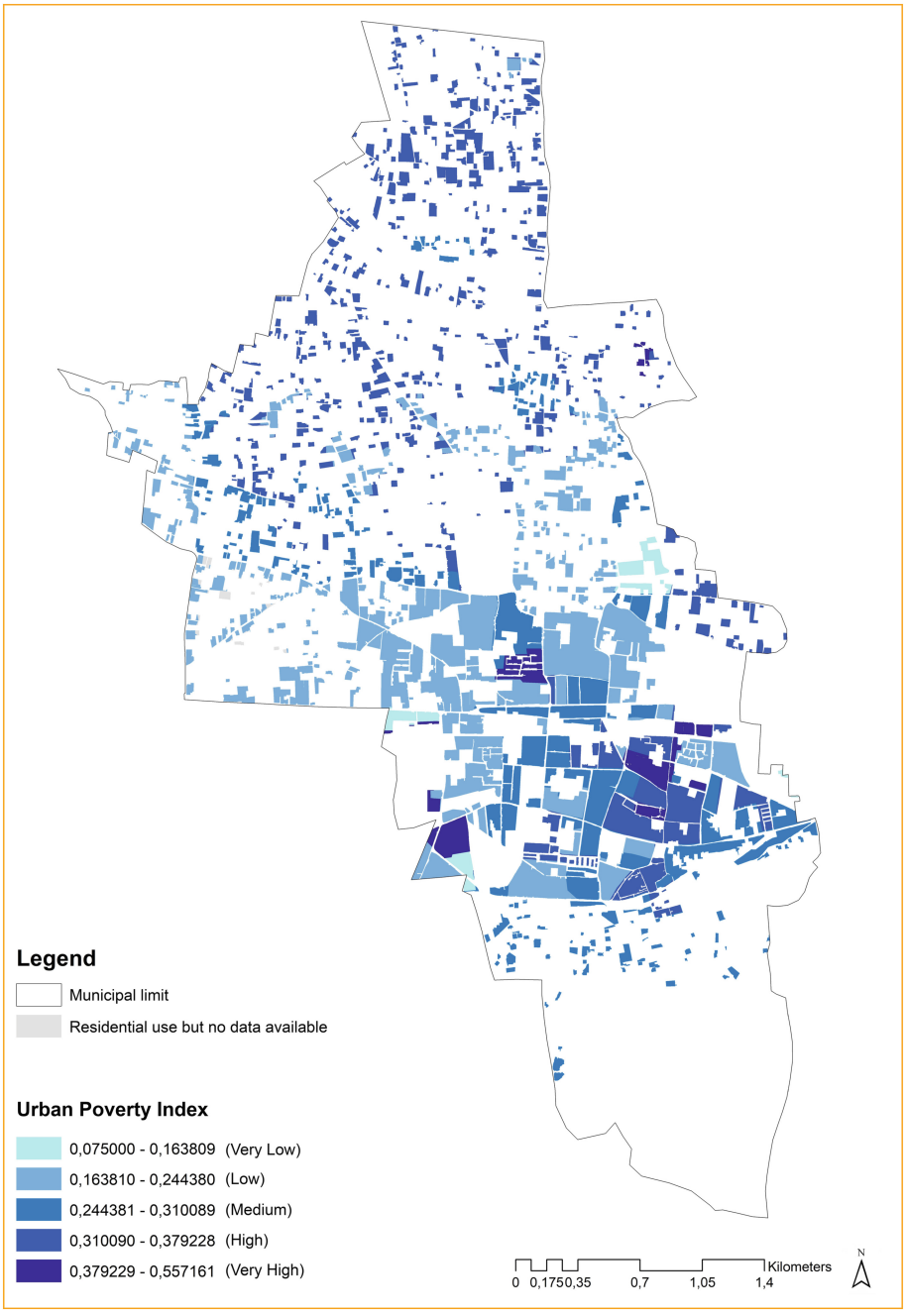

Fig. 3. Urban Poverty Map for the study area.

5 Conclusion

In an international context where urban and energy poverty is on the rise, this work proposes a model for the construction of a composite index of urban poverty, with the aim of detecting low and medium-low income urban areas. The spatialisation of the proposed index allows to obtain a more detailed map of energy poverty with respect to the previously proposed methodology, along the same research project in which the work is framed [8]. In fact, in the previous model energy consumption is evaluated with an articulated methodology, while low-income areas are located quickly in public or social housing districts. Although the results show that the latter is a good criterion to use, especially in the preliminary drafting of the municipal plan, the methodological proposal presented in this article allows to take into account the multiple dimensions of urban poverty in the computation of energy poverty. Consequently, the priority areas map for the promotion of Renewable Energy Communities can also be updated, guiding planning decisions in greater depth, which is useful when drafting the definitive plan.

The developed methodology for the aggregation of the basic indicators is easily practicable in the ordinary municipal planning activity, which in Italy is already particularly long and articulated. However, it should be noted that it is possible to further refine the methods for combining the input indicators [18, 19], in order to build a more accurate map. This advance represents a possible future development of the work, in order to improve the reliability of the results obtained.

Since the input data are ordinarily available in municipal planning processes, the proposed method is potentially transferable to other geographical contexts. Furthermore, the methodology is scalable to lower levels of spatial detail, aggregating the results obtained for higher territorial units. In this direction, the methodology exposed can support RECs promotion actions to be framed in territorial planning.

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