TeMA

Journal of
Land Use, Mobility and Environment

print ISSN 1970-9889 e-ISSN 1970-9870
FedOA press - University of Naples Federico II

DOAJ Rivista scientifica di classe A - 08/F1 Scopus WEB OF SCIENCE

Special Issue 2.2024

Urban Inequalities

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TeMA Journal of Land Use, Mobility and Environment

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Published by
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"

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Editor-in-chief: Rocco Papa
print ISSN 1970-9889 | online ISSN 1970-9870
Licence: Cancelleria del Tribunale di Napoli, n° 6 of 29/01/2008

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TeMA
Journal of
Land Use, Mobility and Environment

TeMA Special Issue 2 (2024) 81-96
print ISSN 1970-9889, e-ISSN 1970-9870
DOI: 10.6092/1970-9870/10344
Received 16th October 2023, Accepted 20th May 2024, Available online 30th June 2024

Investigating the spatial distribution of energy poverty. An application to the city of Bologna

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Abstract
Nowadays energy accessibility and affordability are global concerns. Energy poverty and its effects on households have been increasingly discussed in the public debate, as well as addressed by energy and social policies. Nevertheless, measures to tackle energy poverty at urban scale remain fragmented, and they are far to be fully embedded into urban planning tools.
This paper explores a methodological approach to investigate the vulnerability related to energy poverty. It is based on the identification of two main thematic areas of vulnerability (i.e., socioeconomic and energy). For each of these components, a synthetic vulnerability sub-index has been developed, which has allowed the identification of an overall energy poverty vulnerability index, able to detect different levels of energy poverty vulnerability at urban scale.
This approach, combined with a thorough urban analysis, has been applied to the city of Bologna and it has allowed the identification of urban regeneration strategies for each investigated urban area, targeted to the energy poverty-related vulnerabilities detected.
The results are intended to provide evidence on the importance of investigating who the energy vulnerables are and to map the characteristics of the urban areas where they live, in order to support policy makers to better address energy poverty in cities.

Keywords
Energy poverty; Vulnerability index; Urban planning; Spatial distribution; Urban regeneration.

How to cite item in APA format
Manaresi, S. & Santangelo, A. (2024). Investigating the spatial distribution of energy poverty. An application to the city of Bologna. *TeMA - Journal of Land Use, Mobility and Environment*, (2), 81-96. http://dx.doi.org/10.6092/1970-9870/10344

1. Introduction

Worldwide, between 1.25 billion and 3 billion people do not have their own access to energy, most of which are in developing countries (Siksnelyte-Butkiene et al., 2021; Sy & Mokaddem, 2022). Access to energy implies adequate levels of domestic energy services, such as space heating and cooling, water heating, lighting, cooking, and usage of home appliances, which are considered essential for guaranteeing a decent standard of living for citizens (Thomson et al., 2017; Castaño-Rosa & Okushima, 2021). When dealing with the inability of millions of households to access or afford an adequate level of energy services, the so-called energy poverty phenomenon is addressed. Energy poverty represents a concern all over the world, especially in the current world socio-political situation. The COVID-19 pandemic that spread globally in 2020 was followed by a global energy crisis at the end of 2021: energy prices rose significantly, increasing the share of people unable to pay energy bills in many regions. According to statistics, the population unable to adequately warm their homes rose by almost 20%, from 6.9% to 8.2%, during the first year of the COVID-19 pandemic (Wirth & Pforr, 2022).

Energy poverty is a multifaceted phenomenon involving different aspects of people's lives, from social, health and economic, to political and geographical issues. It represents a very discussed and complex subject, which results in a lack of an official definition. A possible one has been given by Bouzarovski and Tirado Herrero as the inability of a household to secure a socially and materially necessitated level of energy services in the house (Bouzarovski & Tirado Herrero, 2017). The difficulty in obtaining the energy needed in the home is strictly linked to a scarcity of resources and inadequate living conditions in the physical environment in which people live.

According to the latest figure available on energy poverty from the European Commission, approximately 40 million Europeans across all Member States, representing 9,3% of the Union population, were unable to keep their home adequately warm in 2022 (European Commission, 2023), and the increase of energy prices worsened with Russia's invasion of Ukraine and COVID-19 crisis has contributed to an already difficult situation for many EU citizens vulnerable to energy poverty. More specifically, in EU Member States, a social energy divide should be acknowledged: on the one hand, a heterogeneous energy poverty periphery in Southern and Eastern Europe (i.e., Poland, Bulgaria, Lithuania, Romania, Croatia, Spain, Italy, and Portugal), where combination of rising prices and inefficient properties are responsible for energy poverty of many households; on the other hand, there is instead the core group of countries in Northern and Western Europe, with relatively low levels of monetary deprivation and energy poverty. In this latter case, minimal degrees of exposure to domestic energy deprivation are notable in Austria, Finland, Denmark, the Netherlands, and Sweden (Bouzarovski & Tirado Herrero, 2017).

Focusing on a national scale of analysis, energy poverty is characterized and influenced by several types of factors, such as space-based factors that are directly coupled with geography (e.g., material and infrastructural characterization of an area), or factors related to the social sphere (e.g., demographic characteristics). This spatial distribution of energy poverty is related to the existence of different local characteristics within districts of the same city. For this reason, some users may require higher levels of consumption and expenditure to achieve the same degree of comfort and well-being, based on age, health, and employment (e.g., households with young children, elderly, or a member with a disability demand more energy services) (Steemers & Yun, 2009, de Meester et al., 2013).

In the case of Italy, Faiella and Lavecchia define energy poverty as a household's inability to buy a minimum basket of energy goods and services, with consequences for their welfare (Faiella & Lavecchia, 2015). In 2019, the Italian Observatory on Energy Poverty (OIPE) was established at the Levi-Cases Centre of the University of Padua. According to the report published in the same year, in Italy in 2017, there were over 2.2 million households in energy poverty, i.e., 8.7% of the total (Faiella et al, 2019). In the last decade, the prices paid by Italian households have risen by 35% for electricity and 23% for gas. The increase in prices, while consumption was broadly stable, has contributed to making energy expenditure one of the main vulnerabilities of households. The incidence of energy expenditure is evidently higher for poorer households, whose condition has worsened in the last decade (Faiella et al., 2019).

The European Commission has recognized that energy poverty is among the major challenges. A review of recent EU climate and energy policy proposals has been performed by Vandyck et al. (2023). Through the adoption of an energy poverty lens, it illustrates that the presence of energy poverty in the policy narrative is stronger in more recent initiatives, suggesting a growing importance and mainstreaming of energy poverty considerations into related policy initiatives. A number of support bodies have also been created to facilitate knowledge-sharing, especially at local level. Initiatives like the Energy Poverty Advisory Hub (formerly the EU Energy Poverty Observatory), the Citizens' Energy Forum and the Energy Poverty and Vulnerable Consumers Coordination Group provide platforms to collect expertise, gather stakeholders and strengthen collaboration to facilitate tackling energy poverty by national, regional and local governments (Vandyck et al., 2023).

Although nowadays there is a widespread acceptance that taking actions at the local scale is essential to realize low-carbon cities that can efficiently save energy, a lack of integration between energy-saving solutions and urban planning continues to affect the work of local decision-makers, technicians, and practitioners (Carpentieri et al., 2023; Guida, 2023). In order to pursue together social, economic and environmental goals, energy-related issues should be embedded within the urban planning process (Papa et al., 2014; Gargiulo & Russo, 2017; Isola et al., 2023). To do so, there is an increasing need to know future energy-related scenarios, starting from where and how energy is consumed in relation to the configurations of urban fabrics and the socio-economic characteristics of the city (Perera et al., 2021). In addition, better knowledge on energy use and energy poverty will support the more efficient allocation of resources and direct policy interventions (Gaglione & Ania, 2022; Guida & Martinelli, 2023).

What emerges from the study of the recent policies and programmes put in place to address energy poverty, and the tools and measures widely adopted at local level, is the absence of an unambiguous method for mapping energy poverty on the ground, quantifying its effects and specific problems, and allowing specific targeted and effective strategies.

The methodological approach proposed in this paper allows mapping the vulnerability linked to energy poverty through specific sub-indexes. The proposed method, applied to the city of Bologna, is based on the categorization of energy poverty vulnerability into two thematic fields (i.e., socioeconomic and energy). For each of the thematic filed, a specific vulnerability sub-index is elaborated, using the available data. The two sub-indexes derived, through a joint standardization and Budget Allocation Process (BAP) method (Huang et al., 2016), allow the elaboration of a final vulnerability index related to energy poverty, characteristic of each analyzed area. Through the approach used, it is possible to identify the areas of the city of Bologna that are most vulnerable from the point of view of energy poverty, on which an urban analysis is subsequently carried out. The main problems found then allow the identification of diversified and targeted strategies within the urban fabric.

Following this introduction, the second section presents the methodological approach. The third section provides the results of the application to the case study of Bologna, while the fourth one identifies the most vulnerable areas and related criticalities, resulting in differentiated regeneration strategies, and presents four sets of actions based on four urban profiles. The final section provides the main conclusions and limitations.

2. A methodological approach to map energy poverty vulnerability

The first step of the proposed methodological approach consists in identifying the type of data that allows the analysis of all the specific aspects related to the phenomenon itself. For developing the methodology described in this study, the indicators already present in the literature were scanned, identifying the data on which they are based. The main indicators which are reported in the literature to study the energy poverty phenomenon

in the European context are EU-Statistic Income and Living Conditions (EU-SILC) and Household Budget Surveys (HBS) (Tirado Herrero, 2017).
The EU-SILC indicators consist of a harmonized questionnaire including consensual indicators (i.e., the ability to keep the home adequately warm and arrears on utility bills). The main data on which they are based are socioeconomic data (e.g., income, age, employment status), health data (e.g. doctor visits, disease rate, access to first aid or hospital stays), building data (e.g., location, typology, size, HVAC systems), other data regarding the user's approach to energy issues (e.g., energy behavior, periods of heating and/or cooling). All these data result in self-reported data, collected through various methodologies (e.g., social services, advice points, helpdesks, surveys, interviews, online platforms for support program applications, and home visits). HBS data are, instead, based on energy expenditure, in particular considering the variables of net income, and household expenditure for electricity, gas, and other fuels. The main considered data are related to energy consumption and energy expenditure, income (e.g., source and amount of income, how many family members receive income) climate (e.g., heating and cooling degree days or season, average outside temperatures, and relative humidity), and building characteristics (e.g., location, typology, size, age, energy performances, HVAC systems).
For the Italian context, the 10% threshold and the Low Income High Cost – Piano Nazionale Integrato Energia e Clima (LIHC-PNIEC) have also been taken into account (Bardazzi et al., 2020). While the former defines a household as energy poor if its members spend more than 10% of their income to maintain an adequate standard of warmth, the latter is composed of the two main contributions of households with a share of energy costs more than twice the average, and those families without heating purchases and total expenditure below the median. Like the HBS indicator, the two additional indicators relevant for Italy are based on energy expenditure, therefore they rely on the same data set typology.
The main categories of interest for this study of energy poverty vulnerability are socioeconomic data of the population and building energy data, resulting in two field of investigation: the socioeconomic field and the energy one.

2.1 Index development

The second step involves the elaboration of a method to compare the collected data, which are heterogenous in scope and measurement units. As shown in Fig. 1, it provides for the breakdown of the available data into two main fields: socioeconomic and energy.
Each field has several variables (i.e., also called analytical indexes) depending on the type of available data. Each variable describes a different aspect of that field, and it has a specific measurement unit. This leads to a variable number n of analytical indexes and, consequently, a total number related to the sum of the variables of each area equal to: $ns+ne$, where:
- ns is the number of available variables for the socioeconomic field;
- ne is the number of available variables for the energy field.
The first step of the method used to sum variables is standardization, which allows the comparison of data belonging to different variables or samples. This procedure makes it possible to verify the variability of the considered data sample, and therefore of the considered random variable. Variability attributes a weight to the random variable: the higher is the variability, the greater is the weight of the variable.
Once the standardization process is applied, the standardized variables can be added together by considering a further weight that can be given to each. This second step consists of applying the Budget Allocation Process (BAP). This method provides for the assignment of a weight to each random variable, based on the importance that is attributed to the variable for the study of a phenomenon. Having to assign a weight to each variable, it is optimal to have no more than 10-12 variables (Chen et al., 2013). Through standardization and the BAP, a synthetic scope sub-index for each of the two fields is identified. The two synthetic sub-indexes (i.e.,

socioeconomic and energy) are then summed up, always through the standardization method and the BAP, to get to the definition of the final energy poverty vulnerability index.
Thanks to the developed method for summing the data and having considered more variables for the elaboration of the final index, it is possible to differentiate the predominant field that contributes to the vulnerability within the final index and the predominant variable within the same field, consequently allowing the identification of the main aspect that causes a vulnerability situation linked to energy poverty.

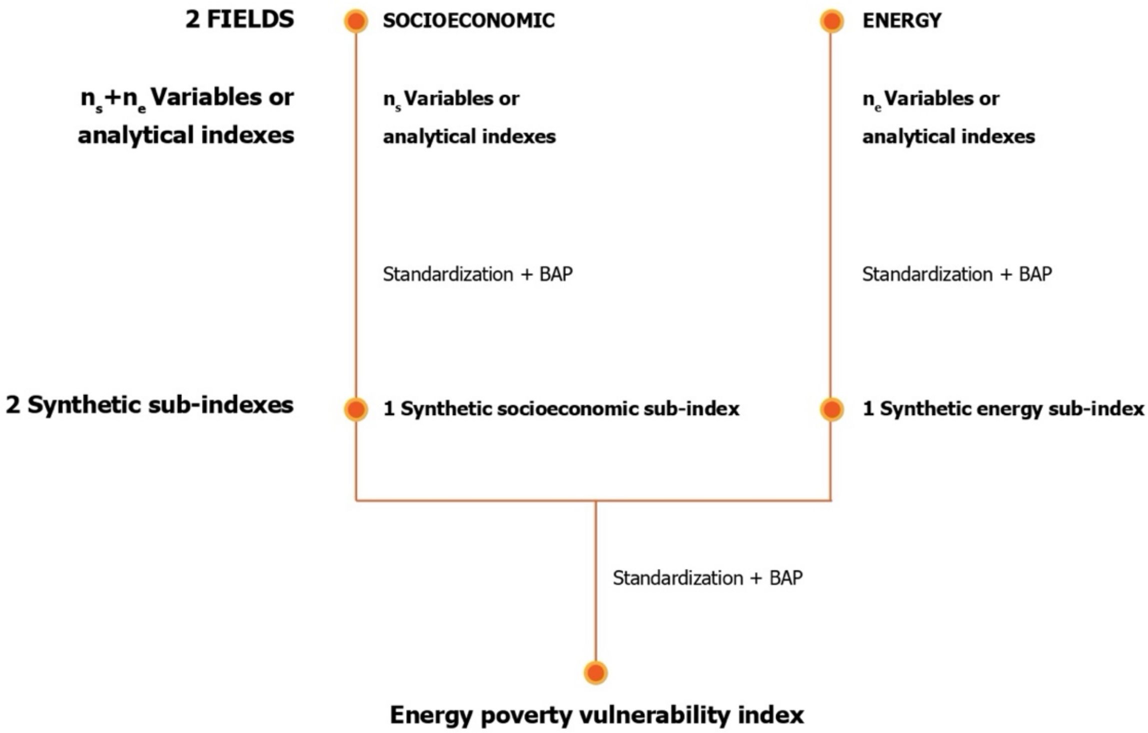

Fig.1 Development of the method to calculate the energy poverty vulnerability index

2.2 Data collection

The socioeconomic data for this study were provided by the Municipality of Bologna. They were collected through surveys, or statistical data at a municipal, regional, or national level. The collected socioeconomic variables are: percentage of people over 65 year old over the total population, population density, percentage of unemployment, percentage of immigrant people (according to their nationality), inhabitants per dwelling, percentage of people with lower education, percentage of households of people living alone, percentage of tenants, percentage of households of people over 65 year old living alone, and income. These data are expressed through a value for each of the 6 districts of the city (i.e., Navile, Savena, Borgo Panigale – Reno, Porto – Saragozza, San Donato – San Vitale, Santo Stefano).
Regarding energy data, the K index used for mapping the energy efficiency of the building stock. The spatialization of K index was retrieved from the Bologna urban plan (i.e., Piano Urbanistico Generale - PUG), where a specific factsheet within the "Profile and knowledge" section is devoted to the investigation of energy efficiency of the building stock (Comune di Bologna, 2021a). The K-value represents an average value obtained from the sum of the energy performance of all the available energy performance certificates included in the city block (mediated according to the related usable area) over the city block surface. This type of data is available at much smaller scale than the socioeconomic variables, therefore with greater variability within the same district.

2.3 Urban analysis

Once the index processing is achieved, the vulnerability related to energy poverty can be mapped. Data have been processed and then displayed in QGIS. In addition to this, the relevant urban planning instruments were identified and studied, and a thorough urban analysis has been conducted, to study the urban fabric and the main built environment characteristics.

The urban plan for the city of Bologna (i.e., Piano Urbanistico Generale - PUG) has been taken into account as main reference planning tool. It was released in 2021 according to the Regional Law no. 24/2017 of Emilia-Romagna Region. The "Profile and knowledge" and "Discipline of the Plan" sections have been mostly analyzed. Moreover, the provisions included in the Sustainable Energy and Climate Action Plan (SECAP) of Bologna (Comune di Bologna, 2021b) have been taken into account. Although it is a voluntary non-binding tool, it is the main planning instrument concerning actions towards energy transition at local level, formulated by the Municipality of Bologna in 2021 as part the Covenant of Mayors for Climate and Energy network.

The analysis of the urban fabric and main characteristics was carried out through a combination of direct observation and digital maps of the PUG and the SECAP, resulting in the identification of 10 main urban characteristics that need to be investigated for each studied area (i.e., microclimatic fragility; demographic, social, economic fragility; presence of public housing stock; social marginalization risk; predominant land use; building density; building age; building energy performance; soil sealing; presence of green areas).

The microclimatic fragility map is included in the SECAP factsheets. Based on the Microclimatic Well-Being Index (BM) defined in the Building Code of the Municipality of Bologna (Comune di Bologna, 2021a), the city of Bologna is divided into homogeneous classes where the levels of improvement to be achieved in the case of urban regeneration and building retrofit are defined. It is derived from the intersection of temperature data (i.e., surface and air), with the elements that describe the different characteristics of the urban fabric (i.e., degree of plant cover, density of buildings, morphology, and geometry of spaces). The vulnerability of the territory has then been related to the potential loss of well-being of people in case of high summer temperatures. In this way it was possible to identify specific classes of the territory with homogeneous climatic morphology and increasing fragility (Comune di Bologna, 2021b).

Demographic, social, and economic fragility, and the areas at risk of social marginalization have been retrieved from the PUG, as well as the presence of public housing stock, the building density and the building age. These five characteristics that involve both the social and housing dimensions have been investigated due to the relationship that has been reported in literature between poor social, economic and housing conditions and energy poverty (Llera-Sastresa et al., 2017; Santangelo & Tondelli, 2017; Aranda et al., 2017; Vurro et al., 2022).

In addition, the predominant land use, the degree of soil sealing, the presence and condition of permeable areas and green spaces were taken into account through direct observation. Lastly, the energy performance of the buildings was considered through the energy vulnerability map elaborated in Section 3.1 linked to the K index reported in the PUG.

3. Results

3.1 Energy poverty vulnerability index development

For the development of the socioeconomic sub-index, the first step was to check the consistency of the variable behavior. All the chosen variables, except income, were consistent with each other: as the number that identifies them increases, the vulnerability condition linked to the socioeconomic component also increases. Income, on the other hand, was inconsistent from this point of view because, if it increases, the condition of vulnerability decreases.

Then the standardization process was applied: for each variable, the average and the standard deviation of the 6 districts were initially calculated and then the standardization formula was applied. The synthetic socioeconomic sub-index was finally calculated for each district by applying the respective weight to the standardized values of each variable. The found term was added in the case of consistent variables or subtracted in the case of income. The range of values obtained was then expressed between 0 and 100. The final values of the synthetic socioeconomic sub-index were then reported in QGIS and thus allowed the mapping of the sub-index on the city of Bologna, as shown in Fig.2. This map shows the socioeconomic vulnerability component (at a district scale) to be included in the final index of energy poverty vulnerability.

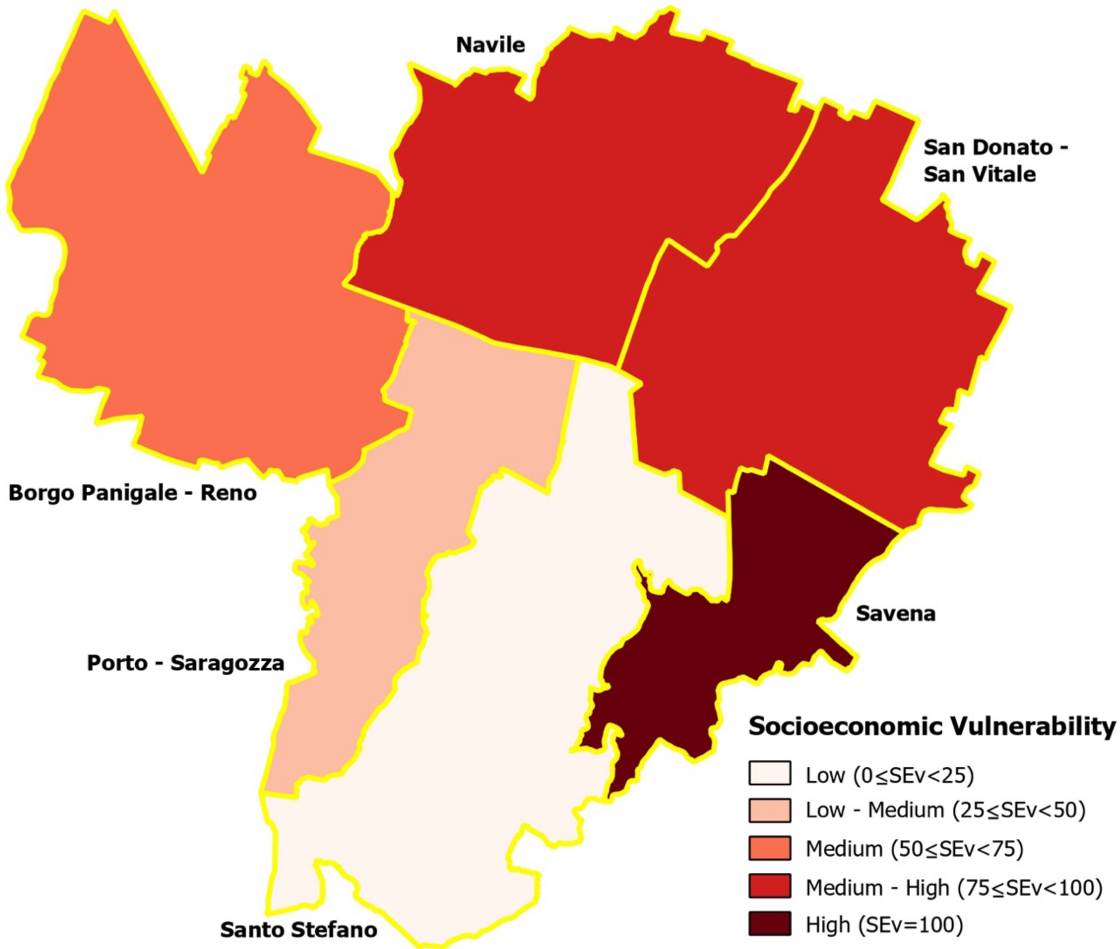

Fig.2 Socioeconomic vulnerability spatial distribution for the city of Bologna. Abbreviation: SEv (Synthetic socioeconomic sub-index)

For the development of the synthetic energy sub-index, the K index was considered and expressed with values between 0 and 100.

The final values were reported in QGIS, allowing the mapping of the sub-index in the city of Bologna at a range scale (as shown in Fig.3). The map includes some unclassified areas due to the lack of input data necessary to calculate the K index related to the area.

For the elaboration of the energy poverty vulnerability index, the standardization of the values of the synthetic energy sub-index was carried out with greater variability of the range scale, and the synthetic socioeconomic sub-index with less variability, being at the district scale. Specifically, for each district, the standardized value of the socioeconomic sub-index was added to the standardized value of the energy sub-index of each range within that district. An appropriate weight was given for each of the two values according to the BAP procedure. The final range of values obtained was between –4,9 and 9,5. In order to make the results comparable to the values of the sub-indexes, the range found was increased to positive values between 0 and 100. The lower value of the initial range found (i.e. -4.9) was added to each test value and was then divided by the constant 0,144 found through the higher value of the new range found (i.e., 14.4), divided by 100.

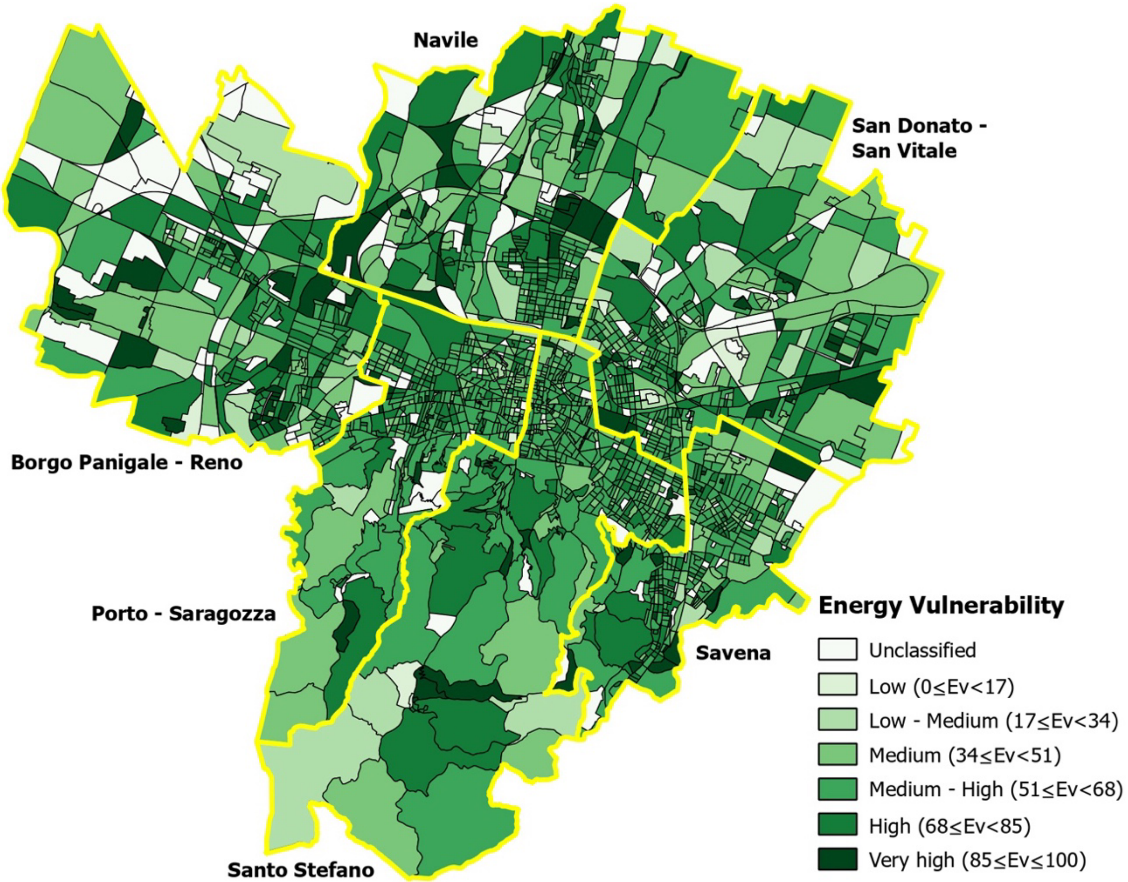

Fig.3 Energy vulnerability spatial distribution for the city of Bologna. Abbreviation: Ev (Synthetic energy sub-index)

The main values for each district and the related number of areas with high energy poverty vulnerability index are reported in Table 1. They have been further analyzed in section 3.2.

Name of the district	Socioeconomic sub-index	Energy sub-index (minimum value)	Energy sub-index (maximum value)	Energy poverty vulnerability index (minimum value)	Energy poverty vulnerability index (maximum value)	No. of areas with a high energy poverty vulnerability index
Navile	96	2	88	15	76	5
Savena	100	12	90	24	78	3
Borgo Panigale – Reno	74	3	100	13	100	1
Porto – Saragozza	49	10	87	13	67	0
San Donato – San Vitale	97	0	86	14	70	5
Santo Stefano	0	4	96	0	72	0

Tab.1 Elaboration of the energy poverty vulnerability indexes

The values of the final energy poverty vulnerability index were then reported in QGIS to map the index distribution in the city of Bologna (as shown in Fig.4). The map presents areas of energy poverty vulnerability ranging from low (values between o and 32), to medium (values between 33 and 66), to high (values from 67 to 100), with few unclassified areas due to the lack of data related to energy poverty vulnerability. The results from the urban analysis described in the following section refer to the areas of high vulnerability only.

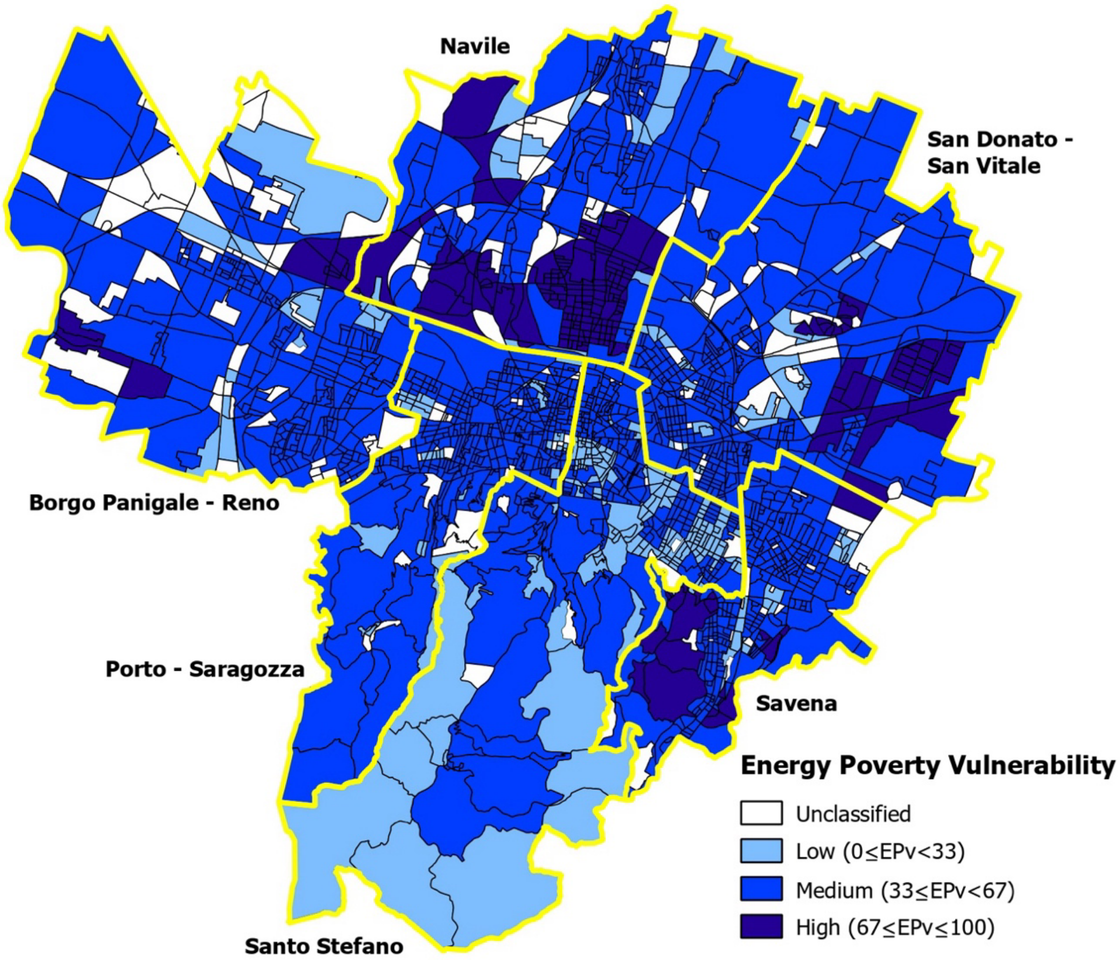

Fig.4 Energy poverty vulnerability distribution for the city of Bologna. Abbreviation: EPv (Energy poverty vulnerability index)

3.2 Identification of key urban characteristics for the areas highly vulnerable to energy poverty

Starting from the energy poverty vulnerability map presented in the previous section and having identified the most vulnerable ranges, 14 main areas have been pointed out as shown in Fig.5. For each of them, a thorough urban analysis was carried out to understand the key urban characteristics that may affect and explain the high values for energy poverty vulnerability. These areas with specific key urban characteristics are reported in Table 2. Among the 10 key urban characteristics identified in section 2.4, the building energy performance is not further investigated and reported as part of the urban analysis, as it has been already considered as part of the energy sub-index used to determine the areas with the highest energy poverty vulnerability. The map thus obtained allows the identification of the most vulnerable areas, displayed in increasing scale color, from least to greatest vulnerability.

As shown in Table 2, there are three areas with exclusively industrial use. Being the focus of this study on household energy poverty, these areas were excluded from further analysis. The identification of the main components of vulnerability allows the elaboration of regeneration strategies and differentiated proposals within the urban fabric, targeted to the level of energy poverty vulnerability embedded in a specific area. This presents many positive aspects, as it allows the allocation of the right resources to specific place-based problems.

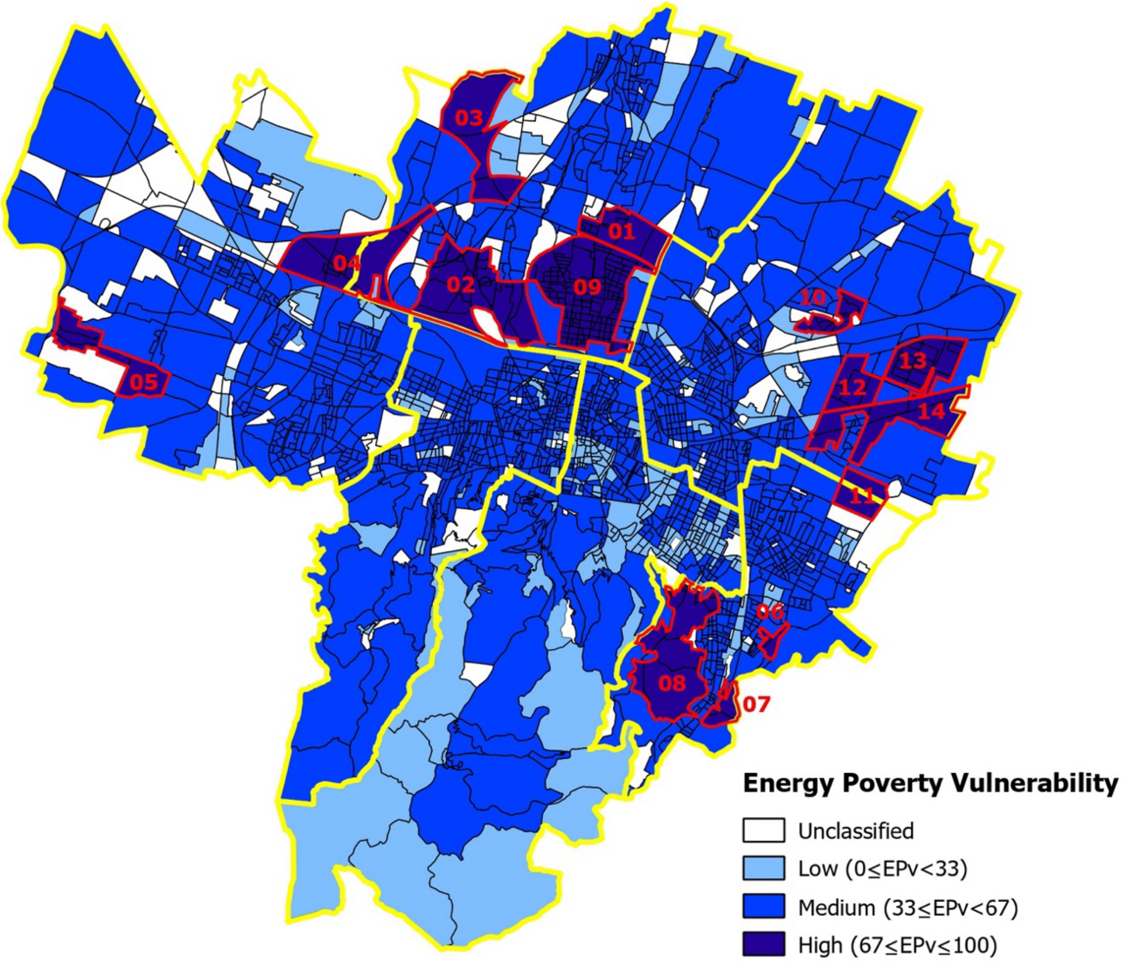

Fig.5 Identification of 14 highly vulnerable areas according to energy poverty index of the city of Bologna

Code	Area	Microclimatic fragility	Demographic, social, economic fragility	Public housing	Social marginalization risk	Predominant land use	Building density	Building Age	Soil Sealing	Presence of green areas
01	**Caserme Rosse – Manifattura**	Medium -High	High	10-20%	No	Predominantly industrial / craftsmanship	Low	1992-2001	High	Low
02	**Ex Mercato Ortofrutticolo – Beverara**	Medium -High	Medium - High	10%	No	Predominantly industrial / craftsmanship	High	1946-1981	High	Low
03	**Tiro a Segno – Laghetti del Rosario**	Low	Medium – High	No	No	Predominantly residential	Low	/	Low	High
04	**Lungo Reno – La Birra**	Medium -Low	Medium - High	No	No	Predominantly residential	Low	1946-1961	Low	High
05	**Rigosa**	Low	High	10%	No	Predominantly residential	Low	Before 1920	Low	High
06	**Corelli 1**	Low	Medium - High	10-20%	No	Predominantly residential	Low	/	Low	High
07	**Corelli 2**	Low	Medium - High	10-20%	No	Predominantly residential	Low	1962-1981	Low	High

08	**Monte Donato**	Low	Medium - High	0-10%	No	Predominantly residential	Low	1920-1971	Low	High
09	**Arcoveggio – Via Ferrarese – Piazza dell'Unità**	Medium -High	High	10%	Yes	Predominantly residential	High	1972-2001	High	Low
10	**Pilastro**	Low	High	20-30%	Yes	Predominantly residential	High	1972-2001	Low	High
11	**Croce del Biacco – Lungo Savena**	Low	Medium	20-30%	Yes	Predominantly residential	Low	1946-1961	Low	High
12	**Roveri 1**	Medium -High	Medium - High	No	No	Exclusively industria	Low	1972-1981	High	Low
13	**Roveri 2**	Medium -Low	Medium - High	0-10%	No	Exclusively industrial	Low	1972-1981	High	Low
14	**Roveri – Croce del Biacco**	Medium	Medium - High	20%	No	Exclusively industrial	Low	1946-2001	High	Low

Tab.2 Description of the 14 study areas according to the main characteristics analyzed

4. Discussion

4.1 Evidence coming from the energy poverty vulnerability distribution and the urban analysis of highly vulnerable areas

From the analysis of the selected highly vulnerable urban areas, it was noticed that, despite they are very different from each other, some of them show common characteristics, allowing the identification of 4 main urban profiles, each with its distinctive features (Fig.6).

Regarding the first urban profile, some general characteristics such as a medium-high microclimatic fragility and a medium demographic, social, and economic fragility are found, while the area is not at risk of social marginalization. Another feature is the low density of residential building stock, and the high age of the building stock. Despite the low density of the building stock, there is 10% of public housing in the total, which is considered to be a medium concentration for the city overall, being the total public housing stock for the city of Bologna about 6% of the total housing stock (Pittini et al., 2019). This profile represents a predominantly industrial-craftsmanship built-up area, causing a high percentage of soil sealing.

The second urban profile is characterized by low microclimatic fragility but a medium-high demographic, social and economic fragility. There is no risk of social marginalization while it presents a low density of residential building stock, with a very high age. Less than 10% of the residential building stock is public housing (i.e., a medium-low concentration), and permeable areas and green spaces are present in large quantities and are relatively homogeneous throughout the area.

The third urban profile provides a medium-high microclimatic fragility, and a high demographic, social and economic fragility. The area is at risk of social marginalization with a high density of predominantly residential building stock, with a scarcity of permeable area, causing high percentage of soil sealing. In addition, there is 10% of public housing out of the total housing units (i.e., a medium concentration).

Lastly, the fourth urban profile presents a low microclimatic fragility but a high demographic, social and economic fragility and a high risk of social marginalization. The area also has a mainly residential building stock with high age, and a high percentage of soil sealing. Around 20-30% of residential units are public housing (i.e., a very high concentration) and many permeable areas and green spaces.

Several possible solutions can be found in the literature and in the urban planning tools to overcome the main problems that contribute to conditions of energy poverty vulnerability. They are further described according to each of the urban profile identified.

Fig.6 Representation of 4 urban profile's main characteristics. The subdivision was made on the basis of the characteristics found for each area in Tab. 2. Areas with similar characteristics were grouped within the same urban profile

4.2 Tailored strategies according to the four-energy poverty vulnerability urban profiles

As for the first urban profile, the high soil sealing of the area is also one of the causes of a medium-high microclimate fragility. Although green areas are present, they are too delocalized. For this reason, a possible strategy could be to carry out new de-sealing interventions by opening new and spread permeable areas and green spaces. Focusing on the residential building stock, presenting poor energy characteristics and very high age, the type of strategy needed could be directed towards building renovation measures.

Regarding the second urban profile, the main issue regards the microclimatic fragility caused by the almost total absence of green areas and permeable spaces and high soil sealing. This can be translated into climate strategies, such as the development of urban green infrastructures by increasing green spaces in new or renovated public areas, planting new trees and conducting de-sealing operations. The high demographic, social and economic fragility, and the risk of social marginalization of the area need to be addressed with socioeconomic strategies. Individual assistance actions such as protection from electrical disconnection or financial aid such as preferential social rates could be significant. Another important long-term strategy could be the creation of energy communities and the involvement of vulnerable households. Strategies such as subsidies and interest-free loans for building energy improvement measures could be crucial. Moreover, awareness-raising and information measures through one-stop-shops, awareness campaigns, and neighborhood workshops could be key factors to enable families to become more conscious of their situation and of any good to save money.

According to the third urban profile, the main issues are the high demographic, social and economic fragility, the high concentration of public housing, and the high risk of social marginalization of the area. As in the previous case, some possible actions could involve an individual assistance, financial aid, awareness-raising and information measures through one-stop-shops, awareness campaigns, and the long-term strategy of the creation of energy communities and related involvement of the vulnerable families. Due to the poor energy performance and the high age of buildings, energy strategies such as the promotion of building renovation measures, integration of renewable energy sources, promotion of devices for energy saving, smart meters, and energy audits could be crucial. As a secondary measure, de-sealing operations with the development of urban green infrastructure by increasing green spaces may be important due to the high degree of soil sealing.
Finally, the fourth urban profile presents low density of buildings and very high age of the building stock. For this reason, strategies such as the promotion of building renovation measures are crucial. In addition, being a high demographic, social and economic fragility area, other possible strategies are directed to the individual sphere, such as individual assistance actions, financial aid, awareness-raising and information measures through one-stop-shops, and awareness campaigns. Lastly, the long-term strategy of the creation of energy communities, as well as individual services aimed to the most vulnerable members of the community such as lonely elderly.

4.3 Embedding the urban regeneration proposals into Bologna planning tools

Urban regeneration calls for tailored renovation approaches based on an accurate data-driven investigation of the urban characteristics and urgent issues. When it comes to better investigating and addressing energy poverty, a number of considerations need to be taken into account to further include provisions for energy poverty vulnerability reduction in the policy and planning instruments of the city of Bologna.
The lack of identification of energy poor people from non-energy poor ones is considered the main weakness. As this research demonstrated, to understand where the population vulnerable to energy poverty lives and who they are is a prerequisite to design tailored strategies. The developed method starts from the identification of the data needed to study the energy poverty vulnerability and it identifies synthetic sub-indexes that can quantify the three main areas that contribute to the condition of energy poverty vulnerability (socioeconomic, energy, and climate fields). It relies on numerical data that describe the phenomenon and, as a consequence, on the identification of energy-poor people from non-energy-poor people. Therefore, the energy poverty vulnerability map should be included in both the PUG and the SECAP.
Another weakness found in the SECAP is the definition of measures and strategies too general when it comes to addressing energy poverty. Starting from the methodology proposed by this study, it would be possible to design actions tailored to different target groups according to the level of energy poverty vulnerability of the area where they live. This is also a weakness that has been detected in the PUG, where a series of strategies for the city of Bologna relating to the key topics of "Resilience and Environment", "Habitability and Inclusion", "Attractiveness and Work" have been identified, together with and a series of local strategies. However, although some strategies related to energy transition are hereby included and they can potentially serve also as measures to address energy poverty, they are neither spatialized, nor enough specific to tackle energy poverty vulnerability. With the proposed method, it would be possible to dive into the urban contexts by diversifying strategies and tailoring them as much as necessary.

5. Conclusions and limitations

This paper addresses energy poverty vulnerability at urban scale. Energy poverty represents the inability of a household to access a minimum level of energy services to meet basic needs such as cooking, lighting, space heating and cooling.

The methodological approach proposed in this study is aimed at better understanding the spatial distribution of energy poverty in cities, by mapping the main vulnerabilities linked to energy poverty through specific sub-indexes. It starts from the identification of the main data needed to study this phenomenon, dividing them into two main fields: socioeconomic and energy data. For each one, the proposed method involves the computation of a synthetic sub-index, using a combined approach of standardization and Budget Allocation Process (BAP). After calculating the synthetic sub-indexes, by the same procedure, the final energy poverty vulnerability index has been obtained. The city of Bologna has been chosen to better investigate energy poverty vulnerability at local scale. An urban analysis, which considers many aspects of possible energy poverty vulnerability, and the analysis of main urban planning tools that the city has put in place have been performed. The results allowed to understand how and to what extent the energy poverty phenomenon is addressed in the current policy instruments and planning tools.

Nevertheless, some research limitations must be acknowledged. In particular, data resolution was varying greatly among the two identified energy poverty-related fields (i.e., socioeconomic and energy). The energy data available were at a higher resolution than the socioeconomic data, and for this reason it was not possible to make a direct comparison between them, leading to less accurate results in the development of the final energy poverty vulnerability index. Moreover, the climatic data were not available for the city of Bologna, neither at district scale, nor at building block level. For further studies, it would be beneficial to include in the analysis the climate field. It would be possible to distinguish two types of sub-indexes: one regarding winter climate vulnerability and the other regarding summer, differentiating the discussion by seasonality. Variables of interest for the study of winter climate vulnerability (i.e., the monthly average temperature of the minimum daily value), and summer climate vulnerability (i.e., the monthly average temperature of the maximum daily value and monthly average relative humidity of the maximum daily value) should be identified.

Concluding, the study demonstrates that, starting from the resulting energy poverty vulnerability map, which divides the territory into areas of low, medium and high vulnerability, is essential to tailor the strategies and measures to tackle energy poverty to the urban profile resulting from the investigation. Evidence from this study may also produce recommendations to further embed the identification of and provisions for energy poverty into the urban planning tools at local scale.

Acknowledgment

The authors thank the Municipality of Bologna for providing the dataset used.

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Image Sources

Fig.1-6: Authors' elaboration.

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