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ORIGINAL ARTICLE

Implications of energy poverty and climate change in Italian regions

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Abstract Energy poverty is one of the main challenges that governments must address. This aspect acquires great relevance if it is combined with the expected climatic evolution trends. These climatic changes can have a major impact in countries with a significant variety of climates, such as Italy. For this reason, in this study, an analysis of the risk of energy poverty disaggregated by the regions of Italy with different climate change scenarios was carried out. For this, statistical data available from the different regions were used, and the Representative Concentration Pathway (RCP) climate change scenarios were considered. The analysis found that the Lombardy region could be one of the regions most affected by energy poverty. This aspect is due to the combination of factors such as the old building stock, energy demand, and the remarkable presence of vulnerable families, which causes a higher risk in the region compared to other Italian regions. On the other side, the study revealed an important risk of energy poverty in the Southern regions, which are characterized by the lowest incomes of the country and are particularly affected by the change in cooling degree days in future scenarios.

Keywords Energy poverty · Italy · Climate change · Households · Energy demand

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Introduction

In Italy, an important document in this matter is the Integrated Italian National Energy and Climate Plan (PNIEC) that defines the tools that the country should equip itself to achieve the European objectives in terms of sustainable energy transition between now and 2030 (Ministero dello Sviluppo Economico 2019) but also the "Strategia Energetica Nazionale 2017." The latter document sets a series of actions to be achieved by 2030, and "its goals are to reduce the energy price and cost gap in comparison with Europe, in a context of international prices increasing; to achieve the environmental and decarbonization objectives by 2030 in a sustainable way; to continue improving the security of supply and the flexibility of energy systems and infrastructures" (MISE & MATTM, 2017). However, this aspect can be complex. Subsidies for energy consumption can cause rebound effects by increasing energy consumption and greenhouse gas emissions.

In any case, at the present mainly due to the emergency derived from the COVID-19 pandemic and the consequent economic crisis, it is not only the planet that is suffering but also the population itself; the number of poor is increasing, and the most affected groups are precisely the most vulnerable (Battle, 2020).

In many countries, including Italy, people were forced to confine themselves to their homes to flatten the epidemic curve and allow hospitals to cope with the increasing number of patients requiring intensive care (March–May 2020) (Vicentini et al., 2020). This emergency led to a decline in employment, which caused a drastic reduction in the income of families, and an obvious increase in the use of homes, with a consequent increase in domestic energy demand, by heating or cooling homes, using hot water, and using the Internet to work or study at home (Battle, 2020). To cope with this situation, many governments decided to implement extraordinary measures to protect energy consumers during confinement, such as the prohibition to stop the energy supply in case of non-payment or the possibility to suspend, reduce, or annul energy bills (Mastropietro et al., 2020).

Already in 2019, according to the Italian observatory on energy poverty (OIPE), more than 2.2 million families, which is equivalent to 8.5% of the total, suffered from inadequate temperatures inside their homes or could not pay their utility bills on time due to financial problems; these are all aspects related to the phenomenon of energy poverty (MISE & MATTM, 2017).

The concept of energy poverty was introduced by Isherwood and Hancock (1979) following the energy-price inflation due to the petroleum crisis. In 1991, the English researcher Brenda Boardman (Boardman, 1991) defined fuel poverty as the situation in which a household needed to spend more than 10% of its income to guarantee an adequate indoor temperature. However, several researchers, including Braubach and Ferrand (2013), Rosenow et al. (2013), and Boardman (2012a), identify the energy poverty situation as being related not only to those households with low incomes but also to the energy efficiency in households as well. In recent years, moreover, several scholars have investigated energy poverty as the households' inability to afford essential energy needs (Boardman, 2012b; Wright, 2008). However, some specific demographic factors such as household size, gender, occupation, and class play an important role (T. M., 2018), and three drivers of energy poverty were identified: low income, high-energy price, and energy-inefficient buildings (Fabbri, 2015; Trinomics, 2016). The issue of fuel poverty is also important as regards the mitigation of global warming. In fact, summer energy poverty could be extended in the next years (Ürge-Vorsatz & Tirado Herrero, 2012; Bartiaux et al., 2017). According to this, more and more studies related to the summer months are appearing (Sánchez-Guevara Sánchez et al., 2019; Tabata & Tsai, 2020) in addition to the studies traditionally focused on winter months (Healy, 2003; Healy & Clinch, 2002). For this reason, in the last few years, fuel poverty has gained relevance in the policies of European countries; the European Union has recognized fuel poverty through the clean energy for all Europeans package (European Commission 2016). This plan proposes various measures to protect vulnerable consumers. Furthermore, each country has regulations which define special electricity prices for vulnerable families (Dubois & Meier, 2016).

The novelty of this study is to set the risk of energy poverty across Italian regions with a special focus on climate change and its influence on vulnerable households in future scenarios. This objective has been achieved by carrying out the analysis of those factors underlying energy poverty in Italy, such as the inefficiency of the built environment or the vulnerability of certain household categories, with a link to the consequences of climate change. As regards the climate variations, an analysis of future climate change scenarios was realized identifying a longer-term climate vulnerability as well.

The paper is structured as follows: the "Energy poverty in Italy" section introduces the methodological approach. The "Methodology" section provides an overview of the research field in the Italian territory including a literature review about energy poverty regarding Italy. The "Results and discussion" section includes the study carried out on the risk of energy poverty in Italy with embracing the analysis of the several risk factors identified. The paper concludes by commenting the results obtained and the possible opportunities for future research.

Energy poverty in Italy

The elimination of energy poverty is one of the main challenges of the coming decades; thus, several European countries have begun to take an interest in the societal issue, as reflected by a growing number of national policy frameworks to define, measure, and reduce the phenomenon (Thomson et al., 2016). The principal aim is to improve people's living conditions and, at the same time, facilitating the path to sustainable development. However, even though energy poverty is an important and generalized problem in many countries, there are still no standard definitions and indicators to measure it across the European Union, and the consequence of this lack is that in some countries, this type of poverty is still not considered as a social problem (Castaño-Rosa et al., 2019).

"In Italy, energy poverty is defined as the difficulty of purchasing a minimum basket of energy goods and services or, alternatively, the condition in which accessing to energy services involves a consumption of resources, in terms of expenditure or income, higher than a socially acceptable value" (Ministero dello Sviluppo Economico 2019). This is the definition given by the OIPE of energy poverty in Italy, although other factors are included in other conceptions of the term, such as the following: (i) the inability to afford adequate warmth in the home (Li et al., 2014) (Felice, 2018), (ii) the situation in which a household needs to spend more than 10% of its income to achieve an adequate indoor temperature (Boardman, 1991), (iii) the delay in the payment of utility bills, and (iv) the occupation of defective dwellings (European Commission, 2010) and the inability to improve them because of economic impossibility or living in a rented house (Thomson et al., 2016).

A topic closely related to energy poverty and the bad state of dwellings is human health. Living in houses characterized by inadequate temperatures increases the risk of diseases and death, especially for the elderly and children (Liddell & Morris, 2010; Oliveras, 2021). In 1989, a study examined the relation between damp and mold growth and symptomatic ill-health in adult respondents and children living in selected areas of public housing in England. The study revealed that living in damp and moldy dwellings had an adverse effect on symptomatic health, particularly among children (Platt et al., 1989). However, it is not necessary to achieve a particularly high temperature to ensure comfort indoor. Recently, the World Health Organization (WHO) established that an indoor temperature of 18 °C is suitable for the health of users (World Health Organization, 2018).

As previously mentioned, Italy is also focusing on the issue of energy poverty. In the PNIEC, in fact, "the goal is to reduce energy poverty by 2030 in a range between 7 and 8% of total households" (Ministero dello Sviluppo Economico 2019):

As many scholars have argued, three are the common factors behind energy poverty: low household incomes, high-energy prices, and energy inefficiency of buildings.

Low incomes "depend on National economy, occupation, social policies, income distribution, etc."; energy prices "depend on World economy, National economy, international and national Energy Market, energy taxation"; and the energy inefficiency of buildings "depend on single building performance, the history of buildings and real estate, building history and tradition, cultural effects, innovative new technologies, and other issues in the construction sector" (Fabbri, 2015).

As stated above, there are still no standard indicators to measure energy poverty across the European Union, and the same happens in Italy, where there is not an official measure recognized by Italian National Statistical Institute (ISTAT). However, as read in the "Report OIPE 2020" (Faiella et al., 2020), since 2017, the Italian government has adopted in its official documents ("Strategia energetica" from 2017 and "Piano nazionale integrato energia e clima" from 2019) a measure proposed by researchers Ivan Faiella and Luciano Lavecchia (LIHC–PNIEC, low-income high-costs indicator–Piano Nazionale Integrato Energia e Clima) (Faiella & Lavecchia, 2014) (Faiella & Lavecchia, 2021). They have modified the minimum-income standard (MIS) indicator and the low-income high-cost (LIHC) indicator to better represent the characteristics of the Italian context. The LIHC-PNIEC indicator is based on real expenditure data (ISTAT) and includes vulnerable families (with an equivalent net expenditure below the median) with no heating expenditure (Faiella & Lavecchia, 2021). This indicator in 2019 placed 8.5% of Italian families in energy poverty. Nevertheless, the use of null heating expenditure as a threshold can be considered a weakness. It appears to be too restrictive in the assessment of families in hidden energy poverty because it excludes numerous families from the analysis. In fact, vulnerable households usually restrain their consumption, but they have null heating expenditure only in extreme and unusual cases (Betto et al., 2020). In this study, however, since it has a statistical data and degree-day approach, the LIHC-PNIEC indicator is not used. Furthermore, this study focuses on the connection among different statistical and demographic factors that can lead to the risk of energy poverty in Italian regions.

Another approach to analyze energy poverty is what the researchers Fabbri and Gaspari use in the city of Bologna; it involves the use of the energy certifications of buildings, the limit energy performance index, and the ISTAT data, and with a GIS system, they map the risk of energy poverty (Fabbri & Gaspari, 2021). Another similar approach was carried out by Camboni et al. (Camboni et al., 2021). In their study, the authors analyzed 19,174 energy certifications from the Treviso region with statistical data. The results showed the importance of substandard housing in the assessment of energy poverty.

In addition to the phenomenon of energy poverty, another important issue already mentioned is that analyzed by researchers Betto, Garengo, and Lorenzoni. It is about hidden energy poverty that could be expressed as the self-imposed restriction of energy consumption to avoid issues related with high-energy bills, a phenomenon which, if not considered in the study of energy poverty, can generate unrealistic results (Meyer et al., 2018; Betto et al., 2020; Barrella, 2022).

Measures to tackle energy poverty in Italy

In Italy, there are three types of policies to tackle energy poverty: reducing energy consumption, improving the energy efficiency of buildings, and granting subsidies to low-income families. To reduce household energy expenditure, there are discounts and deductions that interest electricity and gas bills ("Bonus elettrico" and "bonus gas"), providing a discount that depends on the number of household members and, only for the gas discount, also of the climatic zone and the type of use. This type of support depends on the Italian Equivalent Economic Situation Indicator (ISEE). The ISEE is used to evaluate and compare the economic situation of families who intend to apply for a social benefit at favorable conditions. As regards the above mentioned bonuses, they can be accessed by families with an ISEE value less than 8107.5 €, which can reach 20,000 € in the case of families with more than three dependent children. The bonus for physical discomfort adds a discount to electricity bills or people whose lives depend on medical equipment, regardless of their income. To improve the energy efficiency of buildings, there are regulations, tax exemptions, and energy performance certificate (EPC). The Ecobonus 65% and the Superbonus 110%, for example, are tax deductions for the energy requalification of buildings (OIPE, 2021).

The risk of poverty and social exclusion

In 2019, according to ISTAT, 20.1% of people residing in Italy are at risk of poverty (around 12 million and 60,000 individuals), in other words, they have an equivalent income in the previous year of less than 10,299 € (858 €per month); 7.4% are in serious conditions of material deprivation; and 10.0% live in households with low work intensity; it means with members between the ages of 18 and 59 who, in 2018, worked less than a fifth of the time. The population at risk of poverty or social exclusion is equal to 25.6% (approximately 15 million 390,000 people), and the south is the area of the country with the highest percentage (42.2% in 2019). As regards the vulnerable categories, this study has analyzed some of them considered by ISTAT for its survey on the risk of poverty or social exclusion: households of single people over 65 years old, households with at least one immigrant, households of a single mother, and households of more than five components. In 2019, according to ISTAT, the incidence of the risk of poverty or social exclusion is high among people living in families with five or more components (34.3%), among families with three or more children (34.7%), among people living alone (30.6%), in particular those over 65 years old (32.4%), and among single-parent families

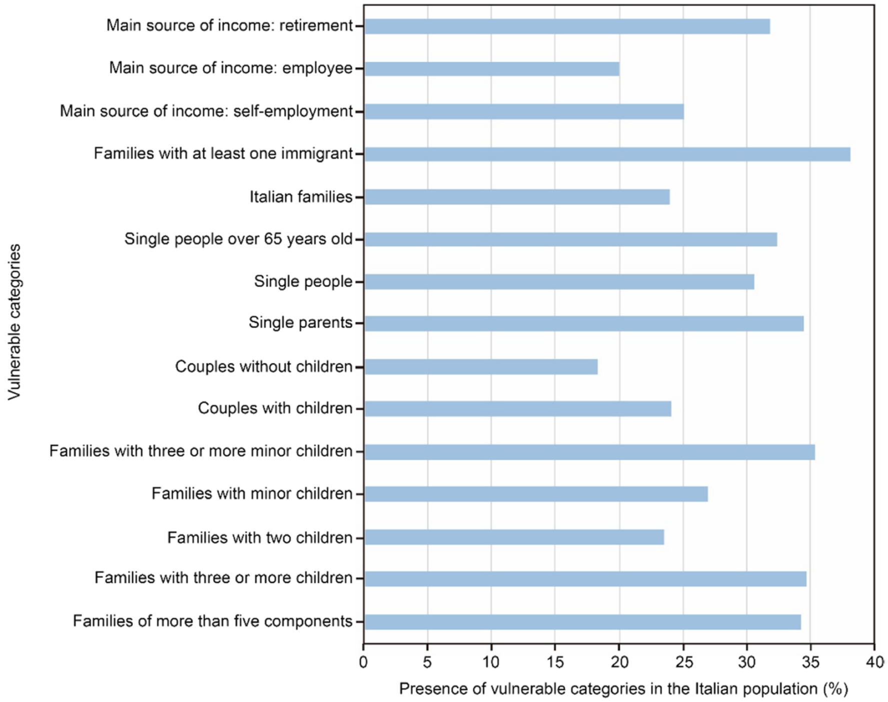

Fig. 1 The risk of poverty and social exclusion (ISTAT, 2019)

(34.5%). The risk is also high among families with three or more minor children (38.8%), which affects more than a third of families, among families whose main source of income is the retirement (33.0%), and among families with at least one immigrant (38.1%) (Fig. 1) (ISTAT, 2019).

The Italian regulatory framework on energy saving

After the energy crisis of the 1970s, the first law on energy saving, 373/76, was enacted in Italy, which concerned, in addition to the heat production systems, the thermal insulation of buildings. In 1991, law 10 of January 9 integrated and partially replaced the law 373/76, introducing a new procedure for energy verification of buildings and taking a first step towards energy certification. Among the goals, there was the following: to introduce uniform rules and procedures to determine the energy quality of buildings and to induce the end user to include the energy parameter in the evaluation of the building. In 1998, the "Riforma Bassanini" transferred the administrative responsibilities for the energy certification of buildings to the regions. In 2005, the legislative decree 192 introduced the methodologies for calculating the energy needs of a building, the minimum requirements, and the energy certification methods for new buildings and partial or total renovations of buildings. It established higher levels of thermal insulation that a building must have and introduced the obligation for new buildings to obtain the energy certification. In 2006, the Legislative Decree 311 extended the energy certification obligation to systems installed in new buildings, to new installations in existing buildings, and to renovation works of existing buildings and facilities.

Methodology

This section explains the methodology followed in the investigation. The analysis was based on the collection of statistical data from official sources and its comparison with estimated data on the energy demand of the Italian built environment. To do this, indicative variables of energy demand were determined through the country's climate. Therefore, no micro-level data at the level of households are used. The analysis was mainly based on a juxtaposition of aggregate statistics at the level of regions and household groups.

Italian regions and climate

This study analyzed the risk of energy poverty in the Italian regions; thus, it is essential to introduce them. Italy is divided into continental, peninsular, and insular, from the North, where it is joined to the European continent, to the South, where ideally constitutes a bridge to Asia and Africa. As regards the subdivision into regions, in Italy, there are twenty regions (Fig. 2), including the Islands. In the Northwest there are Piemonte, Valle d'Aosta, Liguria, and Lombardia; in the Northeast, there are Trentino Alto Adige, Veneto, Friuli-Venezia-Giulia, and Emilia Romagna; in the Center, there are Toscana, Umbria, Marche, and Lazio; in the South, there are Abruzzo, Molise, Campania, Puglia, Basilicata and Calabria; and finally, the Islands are Sicilia and Sardegna.

Fig. 2 Regions of Italy

Table 1 Selected cities in each region

Region	City	Latitude	Longitude	Altitude (m)
Abruzzo	L'Aquila	42.21 N	13.24 E	714
Basilicata	Potenza	40.38 N	15.49 E	819
Calabria	Catanzaro	38.54 N	16.35 E	320
Campania	Napoli	40.21 N	14.15 E	17
Emilia-Romagna	Bologna	44.30 N	11.21 E	54
Friuli-Venezia-Giulia	Trieste	45.39 N	13.46 E	2
Lazio	Roma	41.54 N	12.29 E	20
Liguria	Genova	44.25 N	08.55 E	19
Lombardia	Milano	45.28 N	09.11 E	122
Marche	Ancona	43.37 N	13.31 E	30
Molise	Campobasso	41.34 N	14.39 E	701
Piemonte	Torino	45.04 N	07.42 E	239
Puglia	Bari	41.07 N	16.53 E	5
Sardegna	Cagliari	39.13 N	09.07 E	6
Sicilia	Palermo	38.07 N	13.21 E	14
Toscana	Firenze	43.46 N	11.15 E	50
Trentino Alto Adige	Trento	46.04 N	11.08 E	194
Umbria	Perugia	43.07 N	12.24 E	493
Valle d'Aosta	Aosta	45.44 N	07.19 E	583
Veneto	Venezia	45.26 N	12.21 E	2

To simplify the analysis, the capital of each region was selected for the analysis of climatic conditions. Table 1 indicates the selected cities and their coordinates. In each of these cities, hourly temperature data were obtained during the year. These were generated with Meteonorm as in previous studies (Bienvenido-Huertas et al., 2020, 2021, 2022a, b). Meteonorm software allows generating weather data in EPW format, i.e., EnergyPlus Weather File, for both current and future scenarios. It is backed with a database that counts more than 8000 weather stations worldwide and allows a choice of over 30 weather parameters. The data generated for this study corresponded to both the current scenario and future scenarios. For the current scenario, the Meteonorm data generation with the monitored period between 2000 and 2019 was used. The future scenarios used are described in the "Climate change" subsection.

Climate change

Climate change is a current and urgent issue of global importance. As observed in the IPCC AR5 Synthesis report, "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (IPCC, 2014). The rising temperatures, if not adequately countered, will also transform the performance of the built environment reducing heating strategies. This will imply that the designs must be oriented to reduce the energy consumption of refrigeration. Thus, achieving highly insulated and sealed buildings is not the most appropriate option if climate change is taken into account.

For this, it was essential to make estimates of the variation in energy demand in each of the Italian regions. As climate change scenarios, the Representative Concentration Pathways (RCP) scenarios were used. Three scenarios with a different level of severity of climate change were used: RCP 2.6 (low), RCP 4.5 (medium), and RCP 8.5 (high). These scenarios consider different trends in the evolution of greenhouse gas emissions with an increase in the global average temperature of between 0.3 and 1.7 °C in the RCP 2.6 scenario, between 1.1 and 2.6 °C in the RCP 4.5 scenario, and between 2.6 and 4.8 °C in the RCP 8.5 scenario. Thus, RCP 2.6 is the scenario closest to the Paris Agreement, while the RCP 8.5 scenario is the most unfavorable. Meteonorm allows the generation of climate data for these scenarios using 10 global climate models based on an average of a selection from the Coupled Model Intercomparison Project 5 (CMIP5) (Taylor et al., 2012). For the purposes of this study, future climate data was obtained in the years 2050 and 2100.

The climatic data

The analysis of the energy demand was based on the calculation of the degree days of the selected cities. Degree days are obtained by the cumulative sum of the differential between the base internal temperature and the average external temperature. The degree days therefore represent an index of the climate, and the higher they are, the more energy demand the buildings could have. For the purposes of this study, a base temperature of 20 °C was used. The use of this base temperature value was based on that used by the Italian regulations. In this sense, the regulations use this temperature value to establish the climatic zones of the country (Gazzetta Ufficiale, 1997; Certifico Srl, 2018; Luce e Gas Italia, 2021). So, the heating degree days (HDD) and the cooling degree days (CDD) were calculated with a base temperature of 20 °C (Eqs. (1) and (2)). HDD and CDD were used to find out respectively the heating energy demand and the cooling energy demand for each region. This was based on the use of this type of indicator in other studies related to climate-energy analysis of the built environment (Bienvenido-Huertas, et al., 2020, 2022a, b; Castaño-Rosa et al., 2021).

$$\begin{aligned} \mathrm{HDD} &= \sum_{i=1}^{365} \left(20 - T_{ext,i}\right) \cdot X_{HDD} \\ X_{HDD} &= 1 \ \mathit{if} \ T_{ext,i} \leq 20 \end{aligned} \tag{1}$$

$$\begin{aligned} \mathrm{CDD} &= \sum_{i=1}^{365} (T_{ext,i} - 20) \cdot X_{CDD} \\ X_{CDD} &= 1 \ \mathit{if} \ T_{ext,i} \geq 20 \end{aligned} \tag{2}$$

where $T_{ext,i}$ is the daily average outdoor temperature and X_{HDD} and X_{CDD} are factors used in calculating degree days.

Statistical data

For this study, other types of data, such as the energy source used for the heating system, were not used. This is because it does not represent an added value to the aspects dealt with in the investigation. The analysis of this study has focused on energy demand through climate. Although it is true that energy prices vary depending on the source, the fundamental variable on which research has focused has been energy demand.

Results and discussion

This section provides an analysis of the factors underlying energy poverty in Italy: the energy efficiency of buildings, the vulnerable categories, and the climatic variations that are expected in the coming decades. These factors, referring to the Italian regions, are analyzed from a statistical point of view and compared with each other. The regions in which the simultaneous presence of more risk factors will be higher will be considered a region at risk of energy poverty.

The climate issue in Italy

First, the expected energy demand in the regions based on the climate was determined. For this, the results obtained with HDD and CDD were analyzed. The values of HDD and CDD obtained in each region are shown in Table 2 and in Figs. 3 and 4. The Italian regions that are currently characterized by a high heating demand are Valle d'Aosta with 3525 °C and Basilicata with 3126 °C. On the other hand, the regions characterized by low-heating demand are Sicilia with 863 °C and Calabria with 1509 °C. However, as expected, the values tend to decrease in future scenarios due to rising temperatures. This variation depends on the future scenario analyzed. Thus, the increase in the severity of the climate change scenario implies a greater decrease in HDD. In the RCP 2.6 scenario, the average decreases were 234.2 °C in 2050 and 182.1 °C in 2100 with respect to the current scenario. The stabilization in the climate achieved through policies in accordance with the objectives of the Paris Agreement implies that at the end of the century, there will be a slight increase in the energy demand for heating with respect to 2050. In any case, the HDD values throughout the twenty-first century with RCP 2.6 are lower than those in the current scenario. In the case of the RCP 4.5 and 8.5 scenarios,

Table 2 HDD and CDD obtained in each region

Region	Degree days (°C)													
	Current		RCP 2.6 (2050)		RCP 2.6 (2100)		RCP 4.5 (2050)		RCP 4.5 (2100)		RCP 8.5 (2050)		RCP 8.5 (2100)	
	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD	HDD	CDD
Abruzzo	2051	667	1837	905	1918	902	1798	1013	1567	1225	1697	1085	1202	1868
Basilicata	3126	146	2867	307	2921	269	2766	332	2398	425	2609	385	1915	880
Calabria	1509	657	1308	832	1280	830	1264	891	1019	1091	1202	974	694	1582
Campania	1522	628	1311	855	1343	820	1269	928	1029	1123	1187	1008	726	1711
Emilia-Romagna	2321	598	2112	793	2162	770	2030	877	1788	1071	1889	947	1339	1700
Friuli-Venezia-Giulia	1907	561	1618	780	1725	747	1571	874	1325	1066	1481	941	904	1723
Lazio	1614	797	1381	974	1414	953	1327	1071	1107	1261	1243	1149	784	1860
Liguria	1569	598	1400	784	1443	755	1325	883	1132	1081	1225	998	746	1723
Lombardia	2593	400	2337	587	2418	571	2286	728	2011	855	2180	774	1548	1454
Marche	2261	420	2098	603	2191	616	2003	666	1712	840	1863	761	1313	1485
Molise	2816	253	2591	426	2658	408	2466	460	2150	586	2390	543	1666	1098
Piemonte	2058	527	1770	751	1815	705	1688	861	1456	1052	1605	922	1002	1713
Puglia	1692	488	1463	708	1528	710	1405	747	1153	941	1323	847	809	1504
Sardegna	1555	627	1334	789	1371	770	1279	851	1066	1016	1245	936	785	1499
Sicilia	863	896	744	1045	712	1054	677	1108	478	1322	615	1208	269	1810
Toscana	2259	556	1993	694	2052	680	1892	781	1634	969	1824	902	1213	1621
Trentino Alto Adige	2778	384	2450	591	2501	582	2363	711	2126	879	2281	759	1680	1488
Umbria	2290	547	2095	734	2148	699	2022	799	1735	964	1882	878	1311	1526
Valle d'Aosta	3525	111	3184	224	3273	218	3053	270	2723	366	2911	301	2119	840
Veneto	2680	471	2412	573	2476	555	2342	665	2064	825	2213	783	1622	1495

a clear decrease in HDD was observed: (i) RCP 4.5 obtained average decreases of 308.3 °C in 2050 and 565.9 °C in 2100. Likewise, the maximum values of HDD decrease were detected in the Valle d'Aosta region were 472 °C in 2050 and 801.5 °C in 2100, and (ii) RCP 8.5 obtained average decreases of 406.1 °C in 2050 and 967.2 °C in 2100. Likewise, the maximum values of HDD decrease detected in the Valle d'Aosta region were 613.7 °C in 2050 and 1405.7 °C in 2100. Therefore, the results showed a clear trend towards a decrease in energy demand for heating throughout the country. This aspect was more prominent in regions with a high demand in the current scenario, such as Basilicata and Valle d'Aosta, since it was observed that the largest decreases in HDD were in these regions. These variations showed a limitation that the Italian building energy efficiency regulations have to address. The current regulation is based on a climate classification approach for Italy according to HDD. In each of the climatic zones, limit values are applied for the thermal performance of the envelope. If HDD is expected to decrease significantly in the future, the Italian regulatory approach would quickly become outdated. It is essential to establish a new climate classification criterion and the establishment of limit values that consider new aspects. In this sense, regulations of other countries, such as the Spanish or the Portuguese, carry out climatic classifications based on the energy demand for cooling.

To understand this aspect, the cooling energy demand obtained through CDD was evaluated. In the current scenario, the regions that obtained the highest CDD values were Sicilia (with 896.1 °C) and Lazio (with 797.1 °C). On the contrary, the regions with the lowest CDD values corresponded to the coldest regions: Valle d'Aosta and Basilicata. Therefore, the trends in results between regions show a clear increase in CDD with the future scenarios. Again, the increase trends depend on the combination of scenario and year considered. Thus, RCP 2.6 was the scenario that presented a smaller increase in CDD, because of the effectiveness of climate change

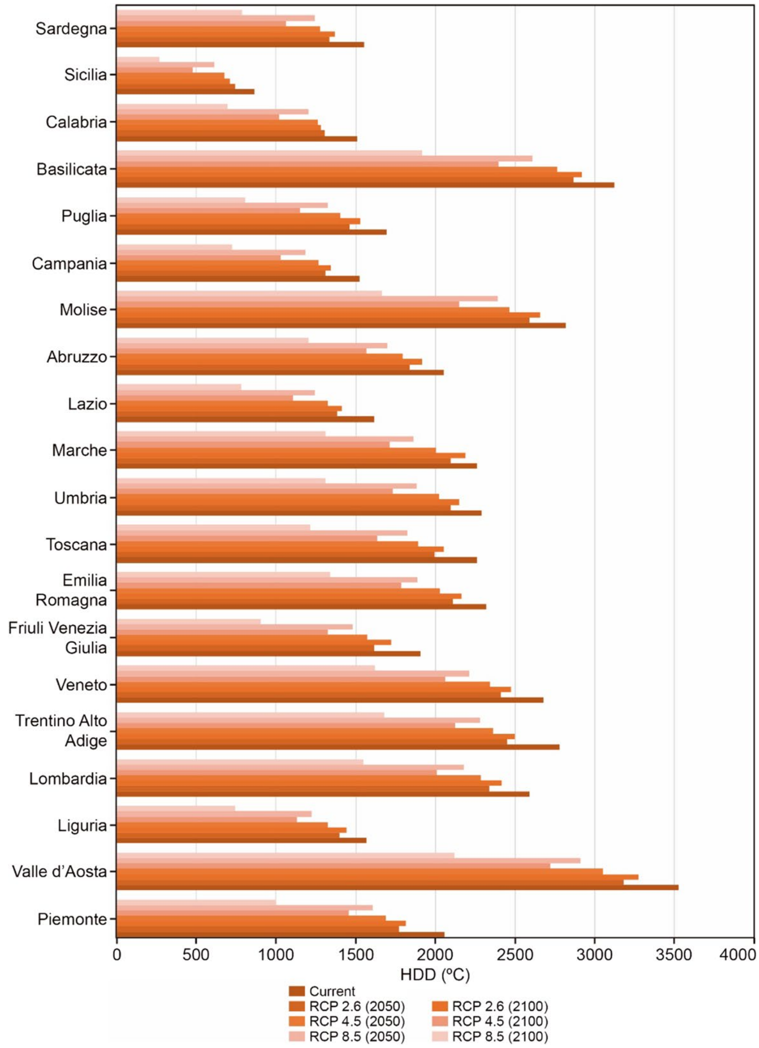

Fig. 3 HDD in Italian regions: current and future scenarios

mitigation policies: an average increase of 181 °C in 2050 and 164 °C in 2100 with respect to the current scenario. In the case of the RCP 4.5 and 8.5 scenarios, the greater severity of climate change was reflected in a significant increase in CDD. Thus, the regions presented average increases at the end of the century of 431.1 °C and 1012.3 °C with RCP 4.5 and with RCP 8.5, respectively. Therefore, these results show the clear trend of increasing energy demand for cooling in the country and highlight the deficiencies that the Italian built environment may present. In this sense, the coldest regions of the country (Valle d'Aosta and Basilicata) may have similar CDD values at the end of the century to the warmest regions in the current scenario (Sicilia and Lazio). This can compromise the performance of the built environment in these regions, which can have high insulation and sealing performance in accordance with the requirements of Italian regulations.

The energy efficiency of buildings

The next factor analyzed is the energy efficiency of buildings. As previously mentioned, before 1976, no attention was paid to the topic of energy saving in the construction sector. Thus, it is important to analyze the construction period of buildings to know the current situation of the residential heritage of the country (ISTAT, 2021b).

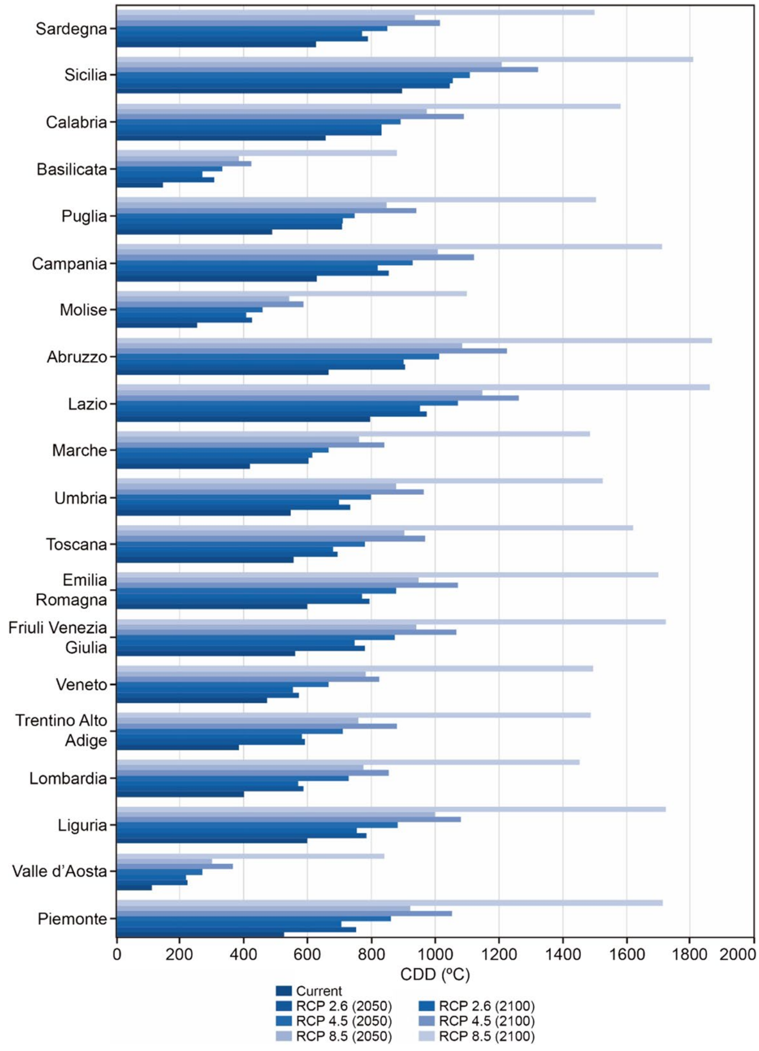

Fig. 4 CDD in Italian regions: current and future scenarios

According to the ISTAT data from the 2011 census (ISTAT, 2021a), all buildings and building complexes add up to around 14.5 million units, 13.1% more than in 2001 census. An important piece of information to analyze is that a quarter of all of them consists of buildings built before 1946 and 15.0% before 1919; this means that most of the Italian residential heritage was built before any law-regulated energy-saving measures. As can be seen in Fig. 5, between 63 and 87% of the built environment of the Italian regions was built before 1976. However, from the estimates elaborated by Italian Center for Economic, Sociological and Market Studies of Construction and Territory (CRESME) (Camera dei deputati XVIII LEGISLATURA, 2020), it appears that the tax incentives for building renovation and energy retrofit have affected from 1998 to 2020 over 21 million interventions. These interventions include those aimed at reducing seismic risk and the requalification of facades. Furthermore, an analysis from the same document confirms a greater use of the incentives by the northern regions and a low use of them from the south and the islands. Thus, it emerges that, despite the numerous interventions, there is a part of the Italian built heritage, especially in the south and in the islands, which has not yet been redeveloped. This could be considered a risk factor for the onset of the phenomenon of energy poverty.

The energy efficiency of buildings in Italy is expressed by the energy performance certificate (i.e., EPC) (ENEA, 2021), which is the information document of the building which shows in a simple and

Fig. 5 Construction period of buildings in Italian regions

intuitive way the energy performance of the building. In other words, it reveals the annual primary energy demand, that is, the quantity of primary energy actually consumed or which is expected to be necessary to satisfy, with a standard use of the building, winter, and summer air conditioning, the preparation of hot water for sanitary use, and, for the tertiary sector, lighting, lift systems, and escalators. Another information reported on the energy efficiency certificate is the nonrenewable energy performance index, which indicates the annual nonrenewable primary energy requirement relating to all the services provided by the technical systems present. This index identifies the energy class of the building on a scale from A4 (the most efficient building) to G (the least efficient building). The energy efficiency certificate also includes the improvement measures that can be carried out on the building to optimize its energy performance and to get a better energy class.

At this point, this study analyzed the situation of three Italian regions: Abruzzo, Emilia-Romagna, and Lazio. Currently, the total number of EPCs made in the Abruzzo region since 2016 amounts to 133,582 units. Since 2013, the total number of EPCs made has increased every year, and the number of them characterized by a high-energy class, from B upwards, has also increased. However, these results are still not satisfactory as the number of buildings characterized by a low-energy class (from C to G) is the vast majority. In 2020, there are 6274 buildings of class G while only 338 those of class A4 (Fig. 6) in a total of 348,493 residential buildings (ENEA, 2019). As regards the Lazio region, the total number of EPCs from 2012 to 2016 amounts to 71,647 units. The situation is similar to the Abruzzo one: the study shows a huge increase in the total number of energy certificates and in the number of those characterized by a high-energy class. In 2016, the number of EPCs from A4 to A1 increases considerably; however, the number of them from C to G almost represents the totality (Fig. 7) in a total of 801,210 residential buildings (ENEA, 2016). The last region analyzed is Emilia-Romagna. The total number of EPCs from 2016 to 2019 amounts to 1,460,826 units. Even though the

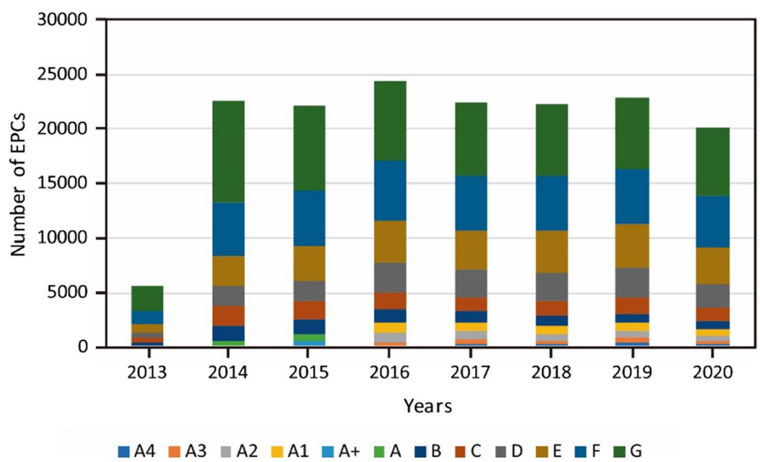

Fig. 6 Number of energy performance certificates per year in the Abruzzo region

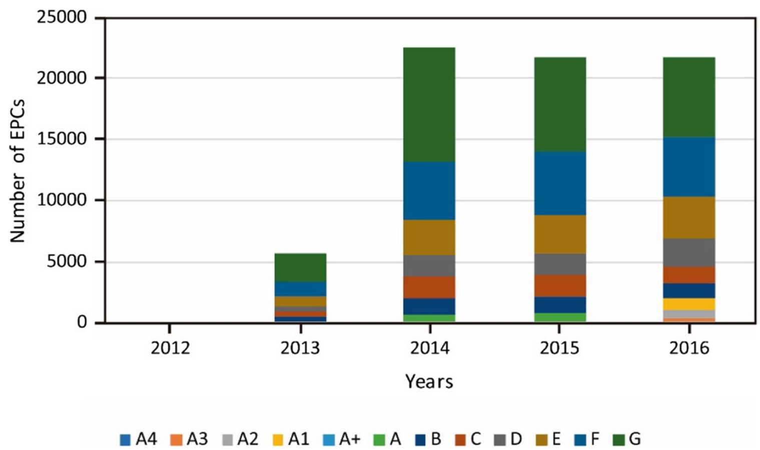

Fig. 7 Number of energy performance certificates per year in the Lazio region

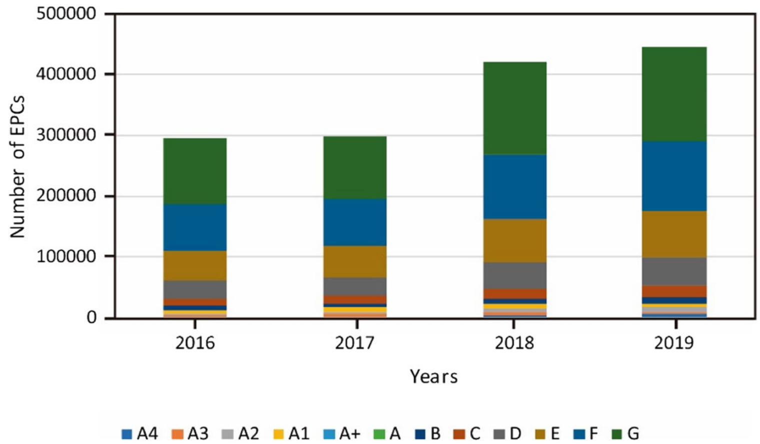

Fig. 8 Number of energy performance certificates per year in the Emilia-Romagna region

number of them characterized by a high-energy class is higher than the other regions, the number of EPCs from C to G is remarkably significant (Fig. 8) in a total of 817,809 residential buildings (ENEA, 2020). The investigation reveals how the situation of the Italian residential heritage in Abruzzo, Emilia-Romagna, and Lazio reflects the hypothesis according to which the presence of a high percentage of buildings built before 1976 corresponds to the presence of energy inefficient ones. The majority of the buildings is characterized by a low-energy class, from C to G, a significant aspect to be considered in the evaluation of the risk of energy poverty as a consequence of higher energy consumption and energy costs. On the other hand, even though the presence of buildings characterized by a high-energy class is still low compared to the totality, it is gradually increasing.

The vulnerable categories

The next factor analyzed corresponds to the vulnerable categories of families and individuals. As already mentioned, this study has analyzed some of the categories considered vulnerable by ISTAT in its survey on the risk of poverty or social exclusion (ISTAT, 2019): households of single people over 65 years old, households with at least one immigrant, households of a single mother, and households of more than five components. In this study, since the authors want to determine the risk of energy poverty in the Italian regions, they have chosen to analyze some vulnerable categories of families and individuals. As these categories are in fact already characterized by a disadvantaged economic and social situation, they can represent a more significant sample than non-vulnerable categories. In other words, if several identified risk factors are concentrated in a region and in addition to that there is a remarkable presence of families belonging to vulnerable categories, it means that in that region, it will be more likely to have a risk of energy poverty.

The analysis has been carried out through an elaboration of the ISTAT data divided by region, regarding the number of individuals belonging to a vulnerable category and average incomes. The heating and cooling demand of buildings in each region considering both current and future scenarios were included. Due to the heterogeneity of the data, the analysis was divided between short and long term for each selected vulnerable group. The short-term analysis concerns the current distribution of vulnerable groups on the territory considering sociodemographic characteristics and incomes. Furthermore, the longer-term analysis introduces the climate factor, both in the current and future scenarios. The first analysis defines the risk of experiencing energy poverty of vulnerable groups in the 20 regions, while the second analysis emphasizes the fact that different regions will not be affected in the same way by climate change.

Households of single people over 65 years old

Short-term economic vulnerability The first analysis carried out is about the households of a single person over 65 years old. The Italian region with the largest number of people belonging to this category is Lombardia with 814,000 out of a national total of 4,582,000, Lazio

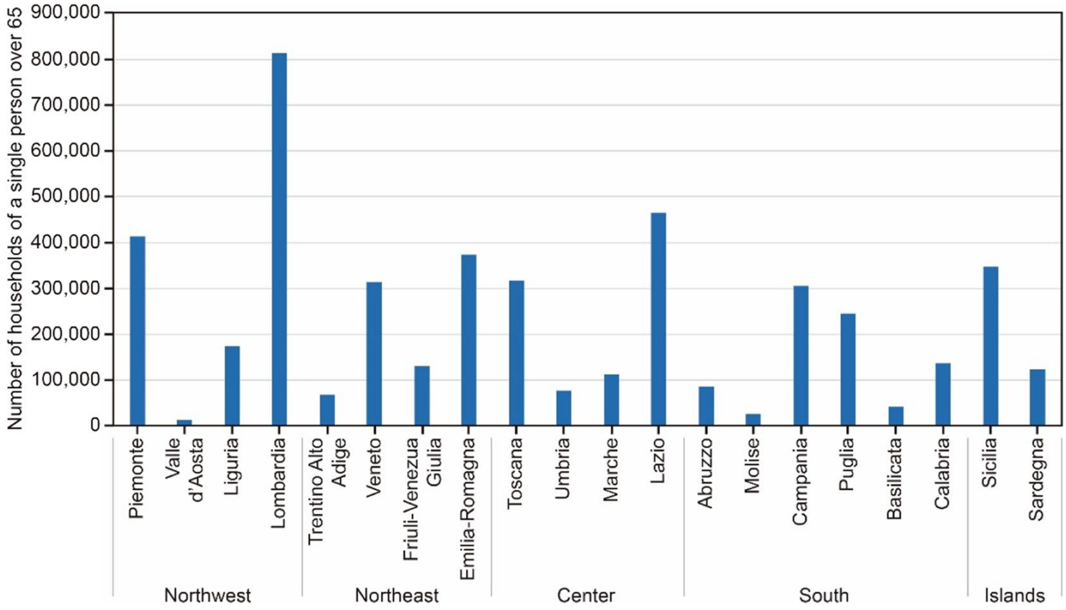

Fig. 9 Number of households of a single person over 65 years old

follows with 465,000 people and then Emilia-Romagna and Sicilia, with respectively 374,000 and 348,000 families. Among the regions with the lowest number, there are Basilicata and Molise, with respectively 41,000 and 26,000 people belonging to this vulnerable category (Fig. 9). The average annual income ranges between 19,367 € in the central regions and 15,281 € in the Southern regions (Fig. 10).

As already mentioned, Lombardia is the Italian region with the largest number of single people over

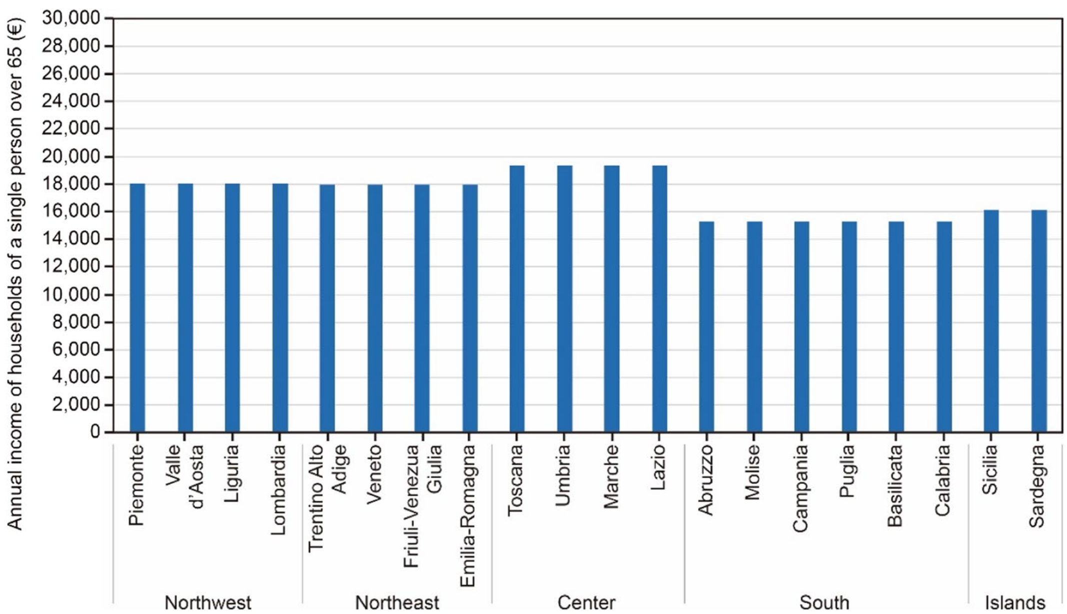

Fig. 10 Annual income of households of a single person over 65 years old

65 years old. It is characterized by a higher annual income compared to most other regions, and it is the fourth Italian region by surface area (23,863 km^2) and inhabitants (9,032,554 people). As regards the Southern regions, Molise and Basilicata record the lowest number of single people over 65 years old, and they are among the regions characterized by the lowest entrances of the country. They are also among the least extensive and the least populous regions of Italy.

Longer-term climate vulnerability Analyzing the heating demand, the study has shown that currently the majority of Italian regions is characterized by remarkable values of heating demand, which decrease in future scenarios. On the other hand, analyzing the cooling demand, the majority of Italian regions records relatively low values of cooling demand. However, observing the future scenarios, there is a significant increase in cooling demand, which is a relevant factor as regards the risk of energy poverty (Fig. 11).

Households with at least one immigrant

Short-term economic vulnerability The second analysis carried out is about the households with at least one immigrant. The Italian region with the largest number of people belonging to this category is

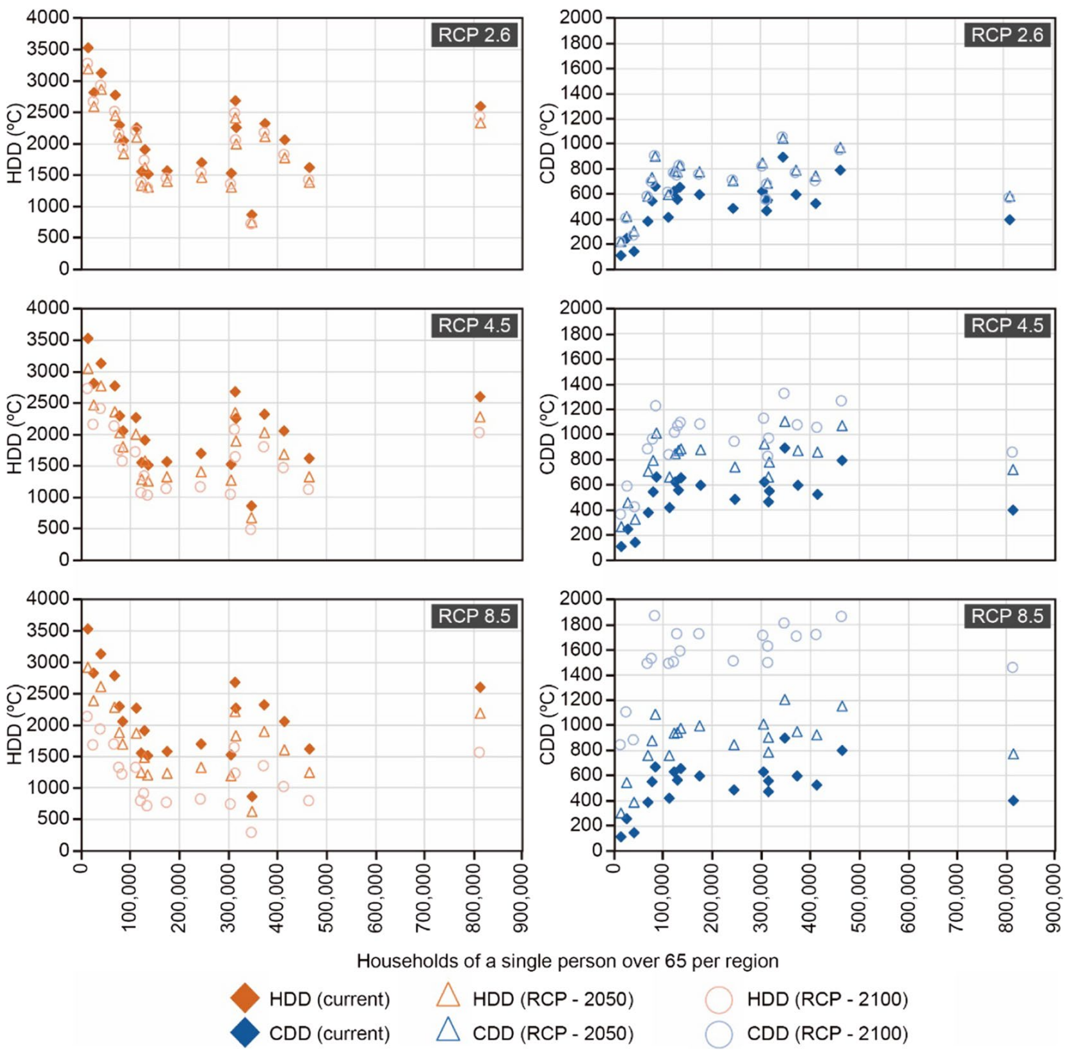

Fig. 11 Heating and cooling demand for households of a single person over 65 years old: current and future scenarios

Lombardia with 400,597 out of a national total of 1,828,338, while Lazio follows with 215,541 families. Among the regions with the lowest number are Basilicata with 7116 and Molise and Valle d'Aosta with 4219 families belonging to this vulnerable category (Fig. 12). The average annual income ranges between 30,701 € in Lombardia and 14,010.92 € in Sicilia (Fig. 13).

The study has shown that Lombardia is the Italian region with the largest number of families with

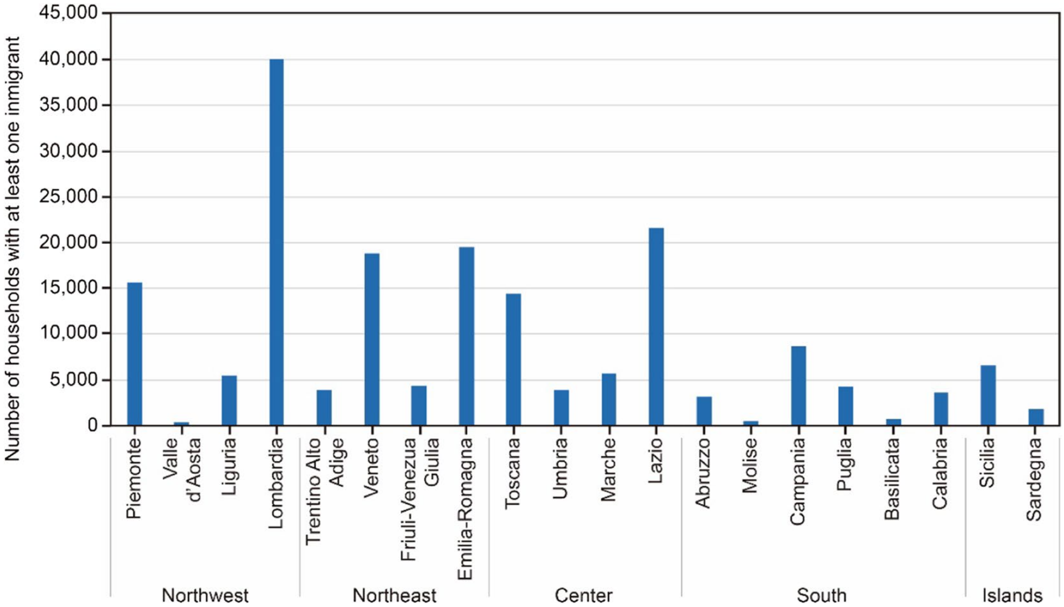

Fig. 12 Number of households with at least one immigrant

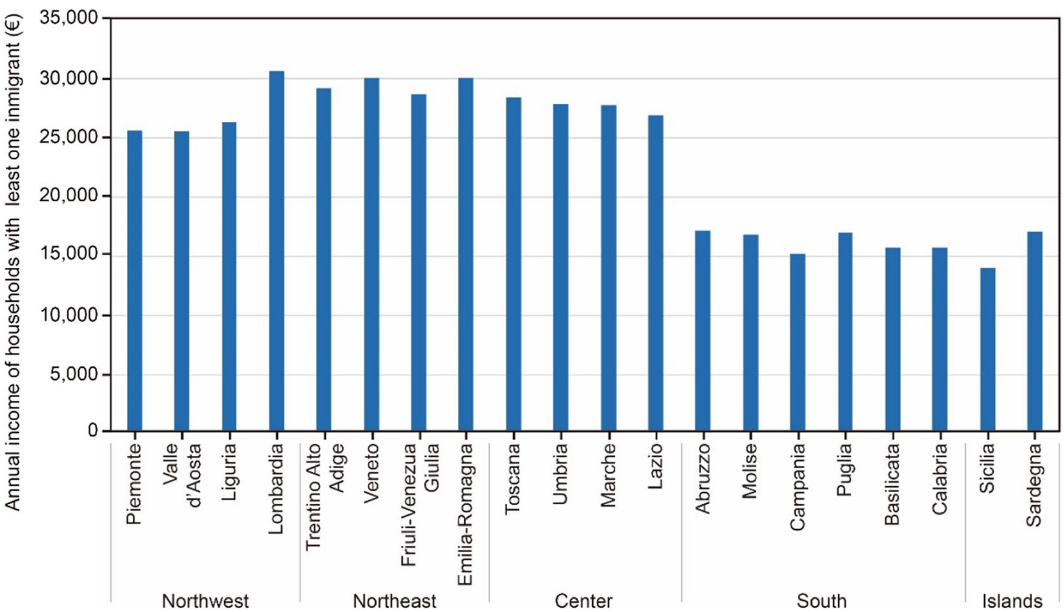

Fig. 13 Annual income of households with at least one immigrant

at least one immigrant. "As a result of immigration flows from a diverse set of countries, Lombardia is the most diverse region in Italy, counting 25% of the country's documented immigrant population and 9% of the regional population" (OECD, 2016). However, in addition to being the most populous Italian region, often chosen by people to live, Lombardia is also characterized by a higher annual income compared to most other regions. As regards the Southern regions, Molise and Basilicata record the lowest number of families with at least one immigrant. They are also among the least extensive and populous regions of Italy, and they are characterized by the lowest entrances of the country.

Longer-term climate vulnerability Analyzing the heating demand, the research has shown that currently the region with the lowest value is Sicilia. However, observing the future scenarios, there is a gradual decrease of heating demand where it tends to zero in Sicilia. On the other hand, analyzing the cooling demand, Italian regions are currently characterized by low values of cooling demand. However, observing the future scenarios, there is a significant increase in cooling demand,

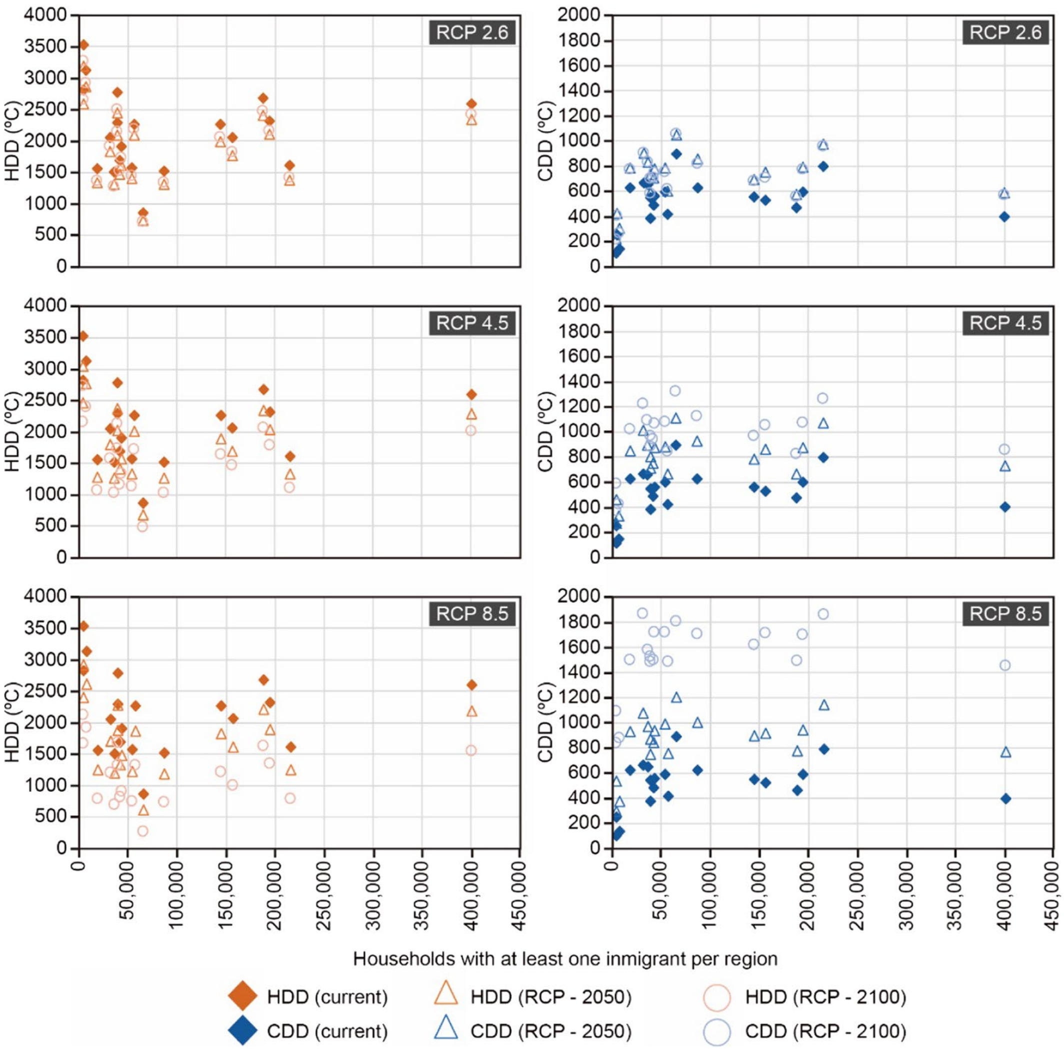

Fig. 14 Heating and cooling demand for households with at least one immigrant: current and future scenarios

evident in the RCP 8.5 scenario, where almost all the Italian regions reach higher values (Fig. 14). As regards the analyzed climatic variations, the Southern regions seem to have a higher probability of experimenting energy poverty.

Households of a single parent

Short-term economic vulnerability The third analysis carried out is about the households of a single parent, including a distinction between

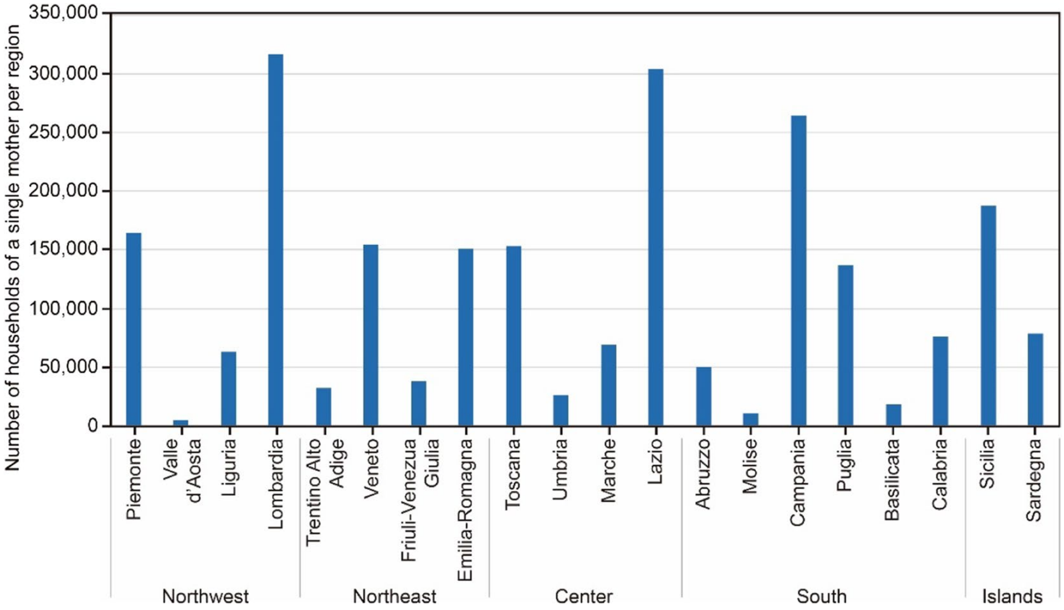

Fig. 15 Number of households of a single mother per region

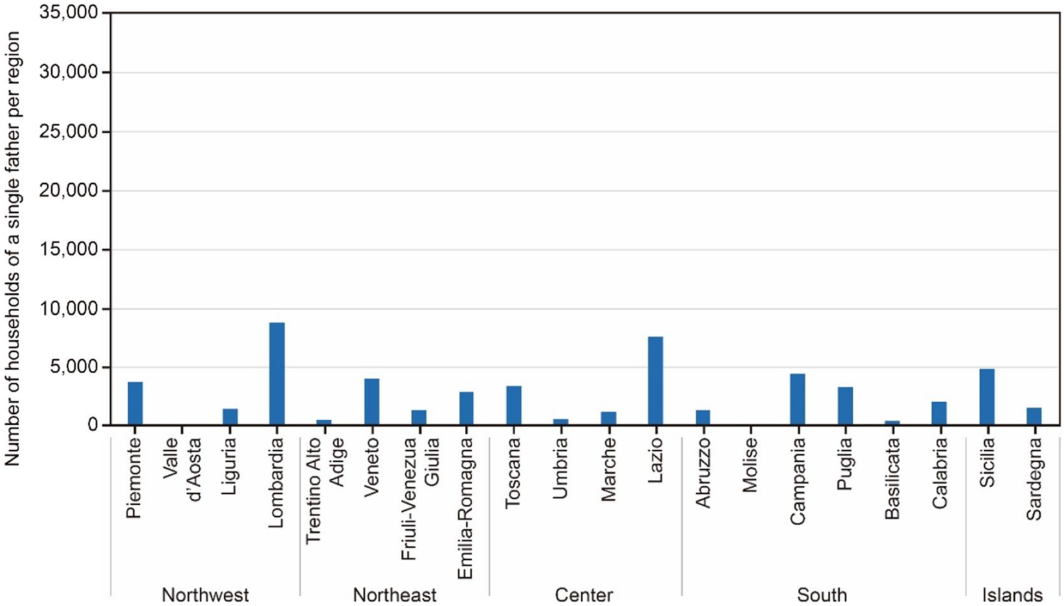

Fig. 16 Number of households of a single father per region

households of a single mother and households of a single father (Figs. 15 and 16). Analyzing the number of households per region belonging to these two vulnerable categories, the study has shown that the presence of households of a single mother is higher than the one of households of a single father. As regards the households of a single mother, the most affected regions are Lombardia with 317,000 families, Lazio with 304,000 families, and Campania with 264,000. Among the regions with the lowest number of families belonging to this vulnerable category, there are Basilicata with 18,000 families, Molise with 11,000 families, and Valle d'Aosta with 5000 families. The average annual income for the households of a single parent with at least one child ranges between 25,108 € in Northeastern regions and 17,159 € in Sicilia and Sardegna (Fig. 17).

As already mentioned, Lombardia and Lazio are the Italian regions with the highest number of households of a single mother. However, they are also characterized by a higher annual income compared to most other regions; thus, the probability of risk of energy poverty in a large scale could be not remarkable. As regards the Southern regions, Campania is the third region for the number of vulnerable families and it is characterized by annual incomes among the lowest of the country. Molise and Basilicata, on the other hand, record the lowest number of vulnerable families, and they are among the least extensive and populous regions of Italy.

Longer-term climate vulnerability Analyzing the heating demand, the research has shown that currently the region with the lowest value is Sicilia. As already observed for the previous vulnerable categories analyzed, regarding the future scenarios, there is a gradual decrease of heating demand due to rising temperatures. On the other hand, analyzing the cooling demand, the majority of Italian regions is characterized by low values of cooling demand. However, observing the future scenarios, there is a generalized increase in cooling demand, which is evident in the RCP 8.5 scenario, where almost all the Italian regions reach significant values (Fig. 18). As regards the analyzed climatic variations, the Southern regions have a higher probability of experimenting the phenomenon of energy poverty.

Households of more than five components

Short-term economic vulnerability The last analysis carried out is about the households of more than

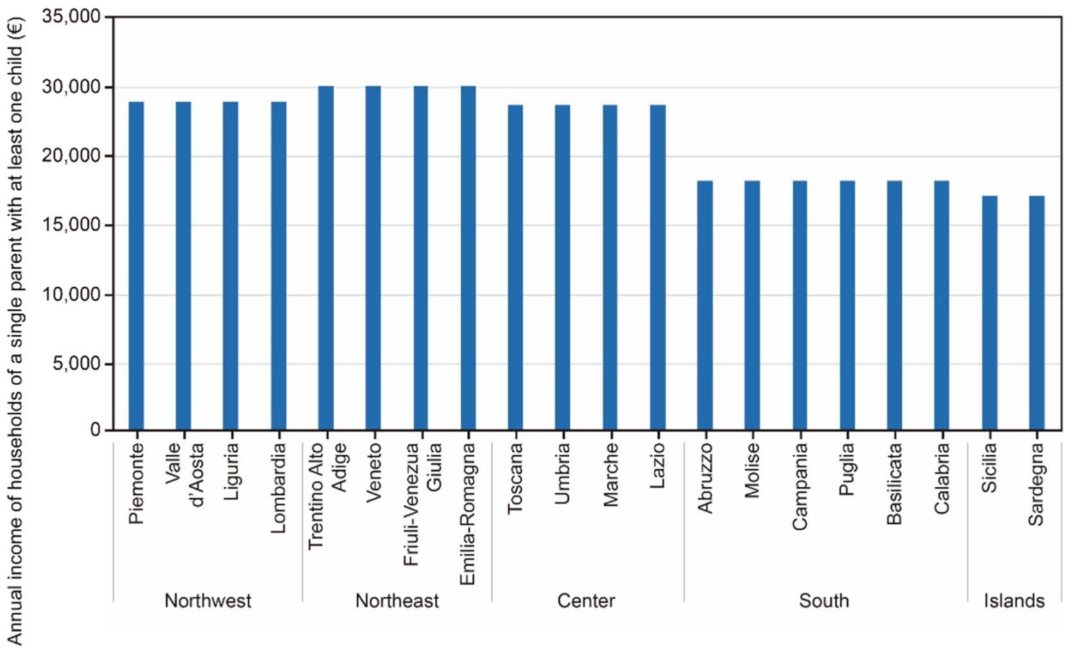

Fig. 17 Annual income of households of a single parent with at least one child

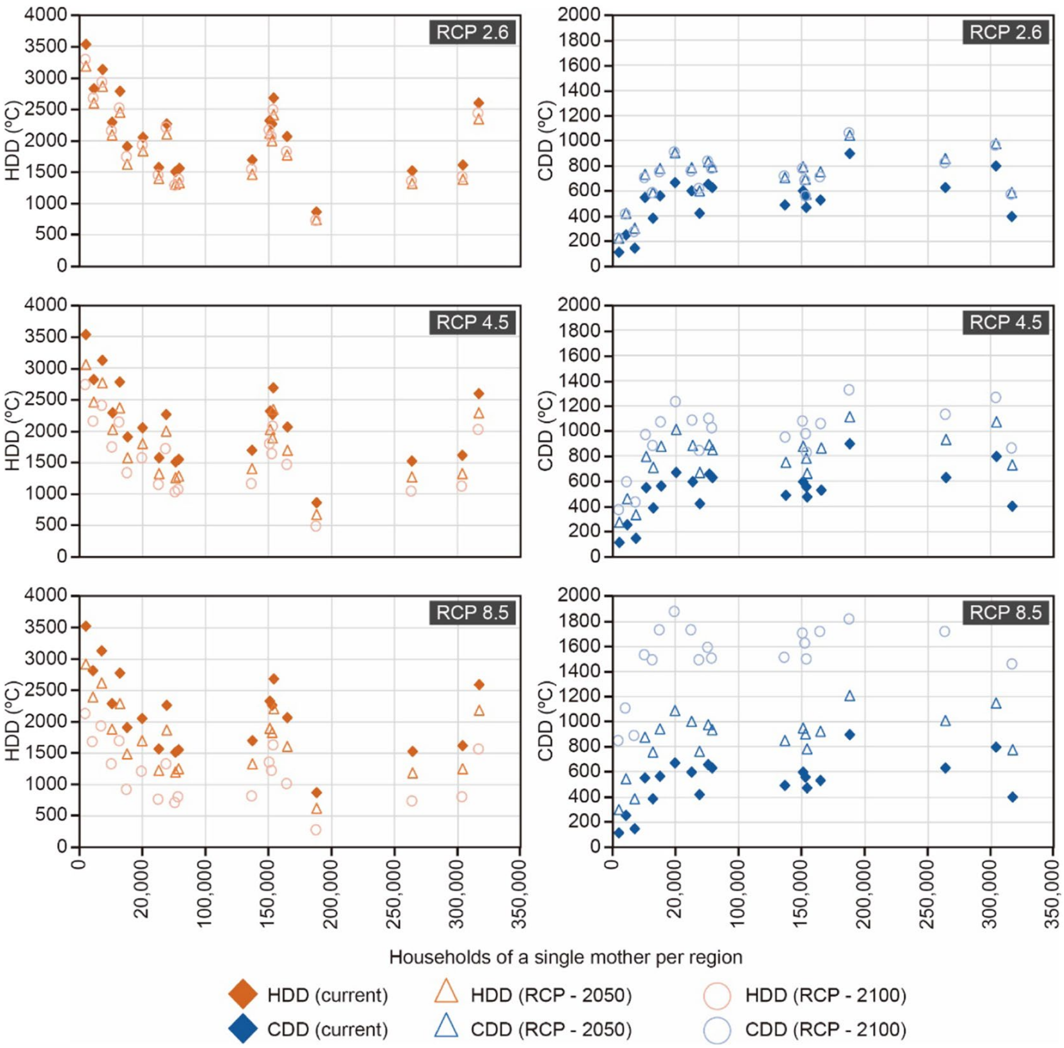

Fig. 18 Heating and cooling demand for households of a single mother: current and future scenarios

five components. The Italian region with the largest number of people belonging to this category is Campania with 210,000 families out of a national total of 1,360,000, while Lombardia follows with 197,000 families. Among the regions with the lowest number, there are Basilicata with 11,000 families, Molise with 6000 families, and Valle d'Aosta with 2000 families belonging to this vulnerable category (Fig. 19). The average annual income ranges between 61,235 €in the Northwestern regions and 34,195 € in the southern regions (Fig. 20).

The study has shown that Lombardia is among the Italian regions with the largest number of families consisting of more than five components. However, as already mentioned, it is among the regions with the highest annual incomes of the country, and it is the most extensive and populous region of Italy. As regards the Southern regions, the case of Campania is quite remarkable; it is the region with the largest number of vulnerable families, and, at the same time, it is characterized by the lowest annual incomes of Italy. Molise and Basilicata, on the other hand, record the lowest number of families belonging to this specific vulnerable category.

Longer-term climate vulnerability Analyzing the heating demand, the region with the current lowest value is Sicilia. However, observing the

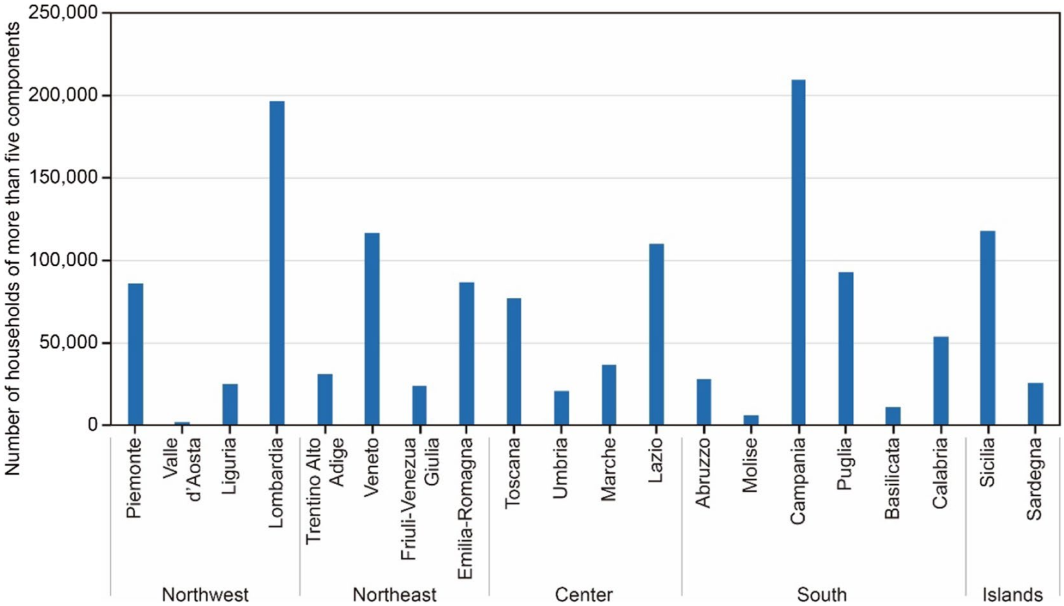

Fig. 19 Number of households of more than five components

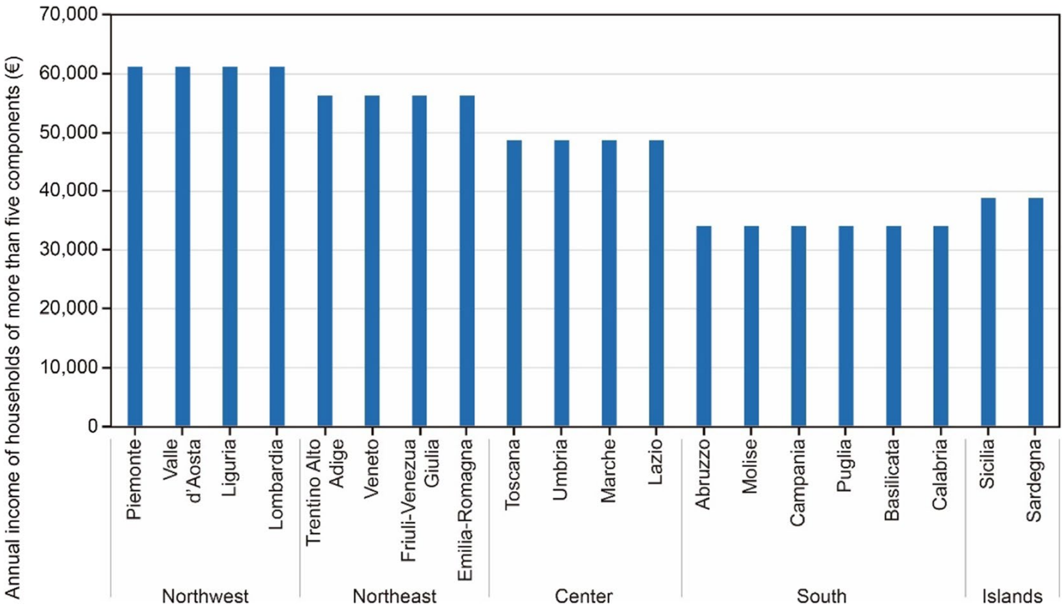

Fig. 20 Annual income of households of more than five components

future scenarios, there is a gradual decrease of heating demand, which is clear in the RCP 8.5, where it tends to almost zero in Sicilia. On the other hand, analyzing the cooling demand, the majority of Italian regions is characterized by low values of cooling demand, which increase in future scenarios where almost all the Italian regions reach considerable values (Fig. 21). As regards the analyzed climatic variations, the Southern regions have a higher probability of experiencing the phenomenon of energy poverty.

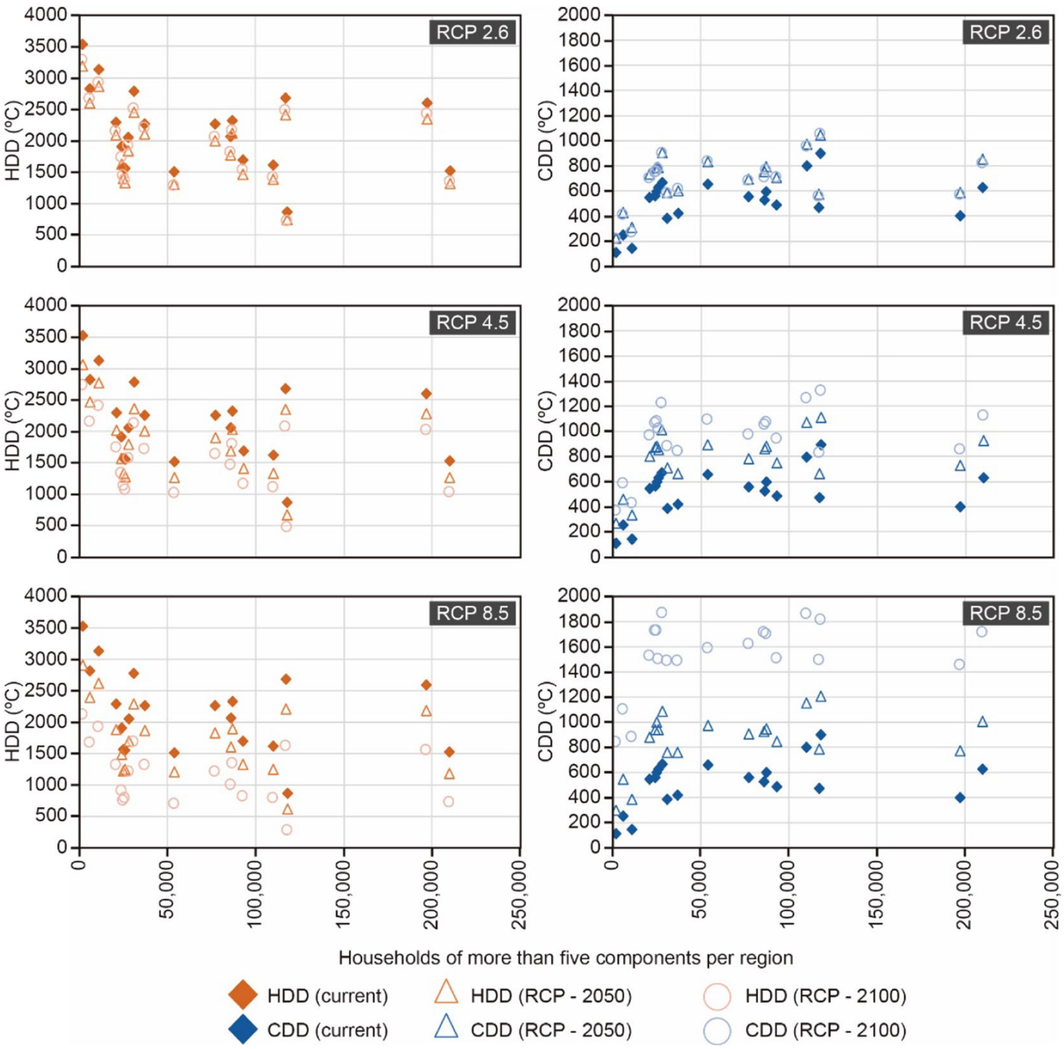

Fig. 21 Heating and cooling demand for households of more than five components: current and future scenarios

Limitations of the study

Some limitations are associated with the research. First, it is convenient to highlight the limitations associated with the threshold value used for the calculation of HDD and CDD. Although this value is established by Italian regulations, it is to be assumed that different threshold values may vary the results. In this sense, the use of different calculation procedures, such as the one used by Castaño-Rosa et al. (2021) numerical results, may vary. In any case, the trends are expected to continue, so that the differences in HDD and CDD between regions follow the same pattern. Also, it should be noted that the calculations are based on a fixed value of 20 °C. This could lead to variations if the analysis is done with an adaptive pattern (Pérez-Fargallo et al., 2020). These patterns are based on adaptive thermal comfort models, representative of user behavior in naturally ventilated buildings. The use of patterns based on adaptive thermal comfort models could lead to substantial variations in the results. Thus, the differences that may exist in the behavior of users between regions and the threshold values could lead to regions with a high demand detected in the research having lower demands.

Secondly, it is convenient to highlight the limitations associated with the statistical values used. These values refer to the averages of the Italian population in each region. I do not know that they have more information in addition to the average values (e.g., maximum, minimum, standard deviation). Likewise, the data is at a regional scale, ignoring possible variations between regions. Then, in the analysis of the vulnerable categories, it has not been possible to obtain the percentage of households belonging to a certain category by region. It would certainly have been useful to provide a more accurate picture of sociodemographics in Italy, but the database used does not have this information. However, it will be taken into account for future studies. Finally, there is a strong relationship between the relevance of energy poverty in a region and its population. This aspect explains the relevance detected in the Lombardia region compared to the rest. The use of data at smaller scales could suppose an enrichment of the analysis carried out in this study, and that should be addressed in future works.

Likewise, the use of other sources related to the built environment could provide more information about the situation of energy poverty at macroscales. In this sense, aspects such as the HVAC systems present in different regions should be addressed in future studies. This aspect has been developed in other countries (Bienvenido-Huertas et al., 2022a, b; Sánchez-Guevara Sánchez et al., 2020), with the implementation of specified indicators adapted for research.

Conclusions

This investigation sets out to analyze the risk of energy poverty in Italian regions. At first, the study focused on energy poverty and its situation within the European Union, particularly in Italy. The research has shown that there are still no standard definitions and indicators to measure it across the European Union; thus, every country adopts different measures and rate the phenomenon according to several criteria. However, the study has analyzed some factors considered useful to quantify the risk of energy poverty such as the energy efficiency of buildings, the vulnerable categories of families and individuals, and the climatic variations expected for the next decades.

As regards the energy efficiency of the buildings, a relevant factor analyzed is their construction period. The study revealed that most of the Italian residential heritage consists of buildings dated before 1976, in other words, before the first law on energy saving was enacted. However, from the estimates elaborated by CRESME, it appears that the tax incentives for building renovation and energy retrofit have affected from 1998 to 2020 over 21 million interventions. The research found out that northern regions benefited more from the incentives with respect to Southern regions. Thus, it emerges that, despite the numerous interventions, there is a part of the Italian built heritage, especially in the south and the islands, which has not yet been redeveloped and do not adequately respond to the indoor thermal and comfort needs that should be guaranteed. The condition of dwellings is a crucial factor in the analysis of the risk of energy poverty; if the envelope and systems are inefficient, it becomes difficult to maintain optimal indoor temperatures, and, when it happens, high bills are often not tolerable for vulnerable households.

Another factor taken in consideration is the presence of vulnerable categories. The categories analyzed were some of those considered vulnerable by ISTAT, such as the following: (a) the households of a single person over 65 years old, (b) the families with at least one immigrant, (c) the households of a single parent, and (d) the families of more than five components. The study revealed that Lombardia is the Italian region characterized by the most remarkable presence of vulnerable families and individuals for all the categories considered in this paper except for the (d) category where Campania region holds the record. The research also revealed that, for all the categories considered, there is a difference between the north and the south of the country: Southern regions and Islands record the lowest incomes, while northern regions are characterized by the highest incomes. The case of Lombardia, even though it is the most populous region and among the ones with the highest annual incomes of the country, is quite significant in terms of risk of energy poverty if we consider that it is also characterized by a great presence of buildings dated before 1976. Campania and Sicilia, however, are characterized by the lowest incomes of the country, so also in this case the risk of energy poverty, with the inefficiency of dwellings, becomes relevant.

As regards the climatic variations, climate change represents a real problem as well as energy poverty. In order to contribute to this investigation area, this work gives some important contributions to the understanding of the Italian situation and highlights some key issues that policy-makers should take into account for effectively managing consumers in energy poverty. Firstly, the support actions should consider the heterogeneity of Italy, at least at a climate zone level. It is a country characterized by a wide variety of climates, both between regions and between municipalities within the same region. Secondly, the measuring of energy poverty should be related to climate change. As highlighted by the results of this work, climate change will radically transform the performance of the built environment and will emphasize the deficiencies that it may present. In this sense, the coldest regions of the country (Valle d'Aosta and Basilicata) may have similar CDD values at the end of the century to the warmest regions in the current scenario (Sicilia and Lazio). In particular, the research showed a clear trend towards a decrease in energy demand for heating throughout the country, as well as an increase in energy demand for cooling. These variations showed a limitation that the Italian building energy efficiency regulations have to address. The current regulation is based on a climate classification approach for Italy according to HDD. In each of the climatic zones, limit values are applied for the thermal performance of the envelope. If HDD is expected to decrease significantly in the future, the Italian regulatory approach would quickly become outdated. As stated above, it is essential to establish a new climate classification criterion and the establishment of limit values that consider new aspects. Taking climate change into account in the measure of energy poverty would mean being able to predict the risk of energy poverty in the coming decades. This paper could be a starting point for the development of a study on the spatial configuration of energy poverty in relation to climate change in order to predict the variation of some factors that can influence the risk of energy poverty.

Abbreviations *AR5*: **Fifth Assessment Report;** *CDD*: **Cooling degree days;** *CMIP5*: **Coupled Model Intercomparison Project 5;** *CRESME*: **Italian Center for Economic, Sociological and Market Studies of Construction and Territory;** *EPC*: **Energy performance certificate;** *HDD*: **Heating degree days;** *IPCC*: **Intergovernmental Panel on Climate Change;** *ISEE*: **Indicatore della Situazione Economica Equivalente;** *ISTAT*: **Italian National Statistical Institute;** *LIHC*: **Low-income high cost;** *MIS*: **Minimum-income standard;** *PNIEC*: **Integrated Italian National Energy and Climate Plan;** *OIPE*: **Italian Observatory on Energy Poverty**

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Author contribution Berti, K., conceptualization, methodology, formal analysis, investigation, writing — original draft preparation, and writing — reviewing and editing. Bienvenido-Huertas, D., visualization, investigation, validation, and writing — original draft preparation. Bellicoso, A., visualization, investigation, validation, and writing — reviewing and editing. Rubio-Bellido, C., visualization, investigation, validation, and writing — reviewing and editing.

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Declarations

Conflict of interest The authors declare no competing interests.

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