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Energy vulnerability in Mediterranean countries: A latent class analysis approach

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ABSTRACT

The need to protect vulnerable consumers is a priority for the European Commission but defining who is energy vulnerable remains difficult. Thus, in this paper, we provide an overview of energy poverty in 2019 for five Mediterranean countries (Greece, Spain, Italy, France and Portugal) using the EU-SILC database. We overcome a methodological difficulty inherent in pan-European research by developing the same tool, LCA (Latent Class Analysis) for characterizing energy poverty in all countries. Then we provide decision support in terms of energy poverty policy, without arbitrarily defining a binary tipping point. Indeed, we identify three groups with different needs: energy sufficient households, energy-poor households and more importantly, we highlight a third group which we refer to as energy vulnerable, who can easily fall below the radar of policy makers because they are not initially defined as precarious.

1. Introduction

Energy poverty (EP) is a situation where households cannot meet their energy needs, due to the energy inefficiency of their dwellings and/or insufficient income (Thomson and Bouzarovski, 2018). In 2020, 6.9% of European Union residents were unable to heat their homes adequately and 6.5% (~30 million) had arrears on their utility bills, while 14.8% lived in unhealthy homes (66 million)[1] and 21.5% were at risk of poverty and social exclusion. Moreover, the current geopolitical scenario in Europe and the COVID crisis have led to high variability of gas and electricity prices which in turn has worsened the standard of living and purchasing power of European households. Although the situation is heterogeneous across Europe, fighting energy poverty has become a priority for the European Commission (EC), to protect vulnerable consumers in particular, but also to increase energy efficiency, support the energy transition and achieve decarbonization of the economic system.[2]

Unfortunately, vulnerable consumers are difficult to identify for several reasons. Although guidelines and good practices for tackling energy poverty are shared at the EU level, fragmentation of definitions and metrics at the national level makes cross-country comparisons difficult and suggests that energy poverty is not simply a binary phenomenon (Charlier and Legendre, 2019; Charlier et al., 2021). Adopting a single threshold indicator implies neglecting a part of the population which, if not below the threshold, is still vulnerable. This vulnerability has already been defined by Bouzarovski and Petrova (2015), then taken up by Castaño-Rosa et al. (2019) as "the propensity of an individual to become incapable of securing a materially and socially needed level of energy service in the home". By identifying vulnerable households and targeting them when implementing energy policies, policy makers can improve *household resilience* to economic shocks and thus mitigate the costs to society. However, the current literature and national practices in Europe do not identify a clear definition and metric of precariousness and vulnerability regarding consumption of energy services.

Faced with this gap in the literature, we investigate who are the energy poor in five European countries and who are the vulnerable with a unique methodology that allows for both cross-country and time comparisons, using a latent class analysis (Greene and Hensher, 2003). First, assuming the same observable variables describing multidimensional energy poverty in different European countries, we link these characteristics to energy poverty, considered as a latent unobserved

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[1] Energy Poverty Advisory Hub, https://energy-poverty.ec.europa.eu/observing-energy-poverty/national-indicators_en

[2] European Commission recommendation (EU) 2020/1563 of 14 October 2020 on energy poverty

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phenomenon (Charlier and Legendre, 2021). Then we reconstruct classes of individuals with a certain number of similarities in relation to these markers of energy poverty. We emphasize that this methodology does not require setting an arbitrary threshold for being poor, thus overcoming criticisms common to other measurement tools. In addition, it also allows us to distinguish the variables for grouping the different latent classes from the factors that influence the probability of belonging to one class or another.

In this paper, latent class analysis is used to study vulnerability to energy poverty in five Mediterranean countries (Greece, Spain, Italy, France and Portugal), which have many economic factors in common, including the fact that the potential for energy savings in residential buildings is significant and under-exploited (MEDENER, 2014). We base our empirical study on data from the European Survey of Income and Living Conditions (EU-SILC) allowing comparison between countries and over time, thanks to its large scale dissemination.

We contribute to the EP literature in two ways. First, we overcome a methodological difficulty inherent in pan-European research by developing a tool for characterizing energy poverty which can be used for different countries and allows monitoring this phenomenon over time. Then we provide decision support for energy poverty policy, without arbitrarily defining a binary tipping point. Indeed, we identify three groups with different profiles: energy sufficient households, energy poor households and more importantly, a third group which we term energy vulnerable households, who can easily fall below the radar of policy makers because they are not initially defined as precarious.

The rest of the paper is organized as follows. Section 2 presents the multidimensionality of the phenomenon as analyzed in the literature. In the third section, we describe the context in the selected five countries. The latent class analysis is presented in Section 4, and data and variables are described in Section 5. Results are presented in Section 6 followed by a discussion of the household profile in each class (Section 7). We conclude in Section 8.

2. Vulnerability to energy poverty: overcoming a dichotomous classification

In recent years, the energy/fuel poverty literature has flourished and given the current energy price volatility, the issue of energy poverty is expected to become increasingly relevant. The key features on which most researchers agree and are considered well-established are that: a) EP is a multidimensional phenomenon, b) it is difficult to measure, and c) it varies over space and time. At the very least, multidimensionality can be traced back to the classic triad of factors including low income, low energy efficiency and high energy prices. However, these commonly identified causes overlook other determinants that contribute to vulnerability to energy poverty. Following Bouzarovski and Petrova (2015), energy vulnerability originates from a set of factors that include energy efficiency, access and affordability as well as household needs, practices and the ability to invest in energy efficiency and to switch between energy service providers. These additional factors are in turn interrelated with household socio-demographic characteristics, health conditions, energy literacy and regional aspects (urban/rural location, climate and temperature), that could determine a mismatch between the energy requirements of the household and the available energy services. Overall, the multidimensionality of energy poverty characterizes this phenomenon as different from monetary poverty although most countries have long placed energy poverty within the context of overall poverty and have mainly employed social policies to address the problem. More recently, there is a growing consensus that the two issues must be distinguished, as empirical studies offer evidence that energy deprivation also arises in households with disposable income above the poverty line (Legendre and Ricci, 2015; Sánchez-Guevara et al., 2015).

This wider analytical perspective makes it possible to move away from the dichotomous characterization of energy poverty to also consider those groups at risk of falling into energy poverty in the future due to factors which make them vulnerable. This added complexity makes measurement even more difficult. Some studies (Castaño-Rosa et al., 2019; EPAH, 2022; Lowans et al., 2021; Sareen et al., 2020; Thomson et al., 2017; Tirado, 2017) have reviewed the energy poverty indicators and identified their pros and cons. In a nutshell, these metrics are classified into three groups: 1) consensual indicators based on self-reported assessments of thermal comfort, housing conditions and ability to pay energy bills; 2) expenditure-based indicators where energy expenditure is compared to household income; 3) direct measurement of energy requirements which monitors parameters such as humidity and temperature.[3]

Given the multidimensionality of EP, a single indicator can hardly capture multiple aspects and drivers whereas a combination of metrics could be more helpful to reflect the complexity of the phenomenon. Therefore, multidimensional indexes have been proposed by several authors (Berry, 2018; Charlier and Legendre, 2019; Gouveia et al., 2019) where several metrics are combined to calculate a complex indicator. However, even this approach is not without criticism, since an ad hoc system of weights must be chosen to combine the various elements of the index and the lack of comparable data makes it less suitable for replication in different national settings.

All these metrics are constrained by data availability. Generally speaking, several data sources are available in European countries and have been used in national studies as summarized by EPAH (2022) but they are far from adequate for studying energy poverty because in most cases they rely upon surveys that are designed for other purposes. If the scope of the analysis is a comparison between EU member states (Halkos and Gkampoura, 2021; Thomson and Snell, 2013), the only available dataset is the EU-SILC which collects data to formulate some consensual energy poverty indicators (Wirth and Pforr, 2022).[4] While this survey facilitates comparisons between countries, it does not allow for the synthesis of multi-dimensional information and even less for the categorization of households as energy poor by properly integrating all the important dimensions. Furthermore, all these self-reported indicators are framed as dichotomous variables and are unable to capture the entire range of experiences and reasons behind a “yes” or “no” answer, not capturing the intensity of energy poverty (Thomson and Snell, 2013; Tirado, 2017). In terms of the above-mentioned vulnerability factors, EU-SILC microdata enables measurement of affordability and contains indirect information on energy efficiency and needs, while access, flexibility and practices are missing (Thomson et al., 2017). However, some socio-demographic variables related to housing tenure, location and type, health conditions, and family composition can support the identification of energy vulnerable households (Bardazzi and Pazienza, 2017). Nonetheless, with this data it is difficult to estimate hidden energy poverty, that is the self-imposed restriction of energy use (Barrella et al., 2022; Meyer et al., 2018). Indeed, households often employ several coping strategies to reduce their energy spending, such as heating only one room, using less lighting and wearing more clothes (Anderson et al., 2012; Brunner et al., 2012).

3. Energy poverty in Mediterranean countries

As mentioned above, there is agreement among scholars that the main drivers of energy poverty are low-income, high-energy prices and

[3] The direct approach compares actual household energy use to technological minimum requirements. An example is the energy needed to close the gap between the indoor temperature and temperature recommended by health organizations, as WHO. There are significant limitations to estimating energy deprivation using this approach due to limited data. See Tirado-Herrero (2017), Kolokotsa and Santamouris (2015), Healy and Clinch (2002).

[4] Household Budget Surveys are collected at the national level for all European countries but are published in a harmonized dataset only for the years 2010 and 2015.

poor energy efficiency with the obvious influence of harsh or too hot climate. However, these factors can combine in peculiar ways resulting in clusters of countries which, at least in Europe, do not respond to the expected influence of climate. Indeed, the empirical literature and the specific indexes published by the European Energy Poverty Observatory (EPOV) highlight that EP stress is greater in southern and eastern European countries (Bouzarovski and Tirado, 2017). This is true notwithstanding a warmer climate in these areas compared with northern regions. Fig. 1 shows an inverse relationship between the mildness of the climate (as represented by Heating Degree Days) and the main EP indicator used at the international level, the share of the population reporting inability to keep their home adequately warm.

Energy poverty in Mediterranean countries has been shaped by distinctive features such as low energy efficiency of buildings, high residential energy costs, energy import dependency, high income inequality and similar geographic characteristics. These countries (namely Cyprus, France, Greece, Italy, Malta, Spain and Portugal) can generally be considered late-comers in terms of prosperity in Europe, and some of them are also recent EU members: this delay in achieving high average income levels, together with a mild climate, has meant that the problem of residential heating has been neglected by both public policies and household investment choices. The result is poorly insulated homes with a non-negligible share of dwellings still lacking satisfactory heating systems if any. Moreover, all these countries share high income inequality indexes and high energy prices, linked to an almost complete traditional energy dependency (nearly non-existent domestic fossil fuel resources). Finally, it is worth mentioning that on average this group of countries severely suffered from the sovereign debt crisis – Greece most of all (Papada and Kaliampakos, 2020) – with social welfare consequences that can still be found in poverty indicators. Obviously, the group is far from homogenous: France has, on average, the best indicators both for income and energy poverty in the group, despite a high percentage of households reporting a low level of home energy efficiency. Moreover, France is also characterized by large differences between mainland and overseas areas, where both income and energy poverty are widespread (Charlier et al., 2021). Cyprus and Malta, on the other hand, have geographical peculiarities, being very small islands far from continental energy infrastructure. Therefore, in our empirical study we focus on the subgroup of five Mediterranean countries identified by the red dots in the figure above, excluding Cyprus and Malta: Greece, Portugal, France, Italy and Spain.

With the partial exception of France, all countries show an improvement in energy poverty indicators in the observed period - particularly for heating ability and energy efficiency of buildings - after reaching a peak following the social consequences of the sovereign debt crisis. This improvement can be attributed to the general recovery of average household income and to national policies specifically designed to increase energy efficiency and thus indirectly reduce energy poverty. Many of the actions came about thanks to the impetus of European guidelines, which recently received a major boost from the 'Clean energy for all Europeans' package.[5] A further step was taken with the Renovation Wave initiative[6] as part of the EU Green Deal, which focused on eco-friendly building renovations to achieve the goals of economic recovery, meeting emission targets and reducing energy poverty.

As already discussed there is neither a common definition of energy poverty or energy vulnerability nor a specific method of measurement within the European framework, composed of binding regulations and general strategies. Thus, member countries have moved unevenly. France defined energy poverty in the 2010 Grenelle II law, and adopted a threshold indicator based on the energy income ratio. In 2017 the Italian National Energy Strategy introduced a definition based on the combination of low income and high energy costs, including the so-called "hidden energy poor" (Faiella and Lavecchia, 2021; Miniaci et al., 2014). The Spanish national strategy against energy poverty established an official definition in 2019, and four selected indicators of the European energy poverty observatory were adopted. Greece published its national action plan for the alleviation of energy poverty in 2021, entailing a combination of two measures, one expenditure-based indicator and one based on required energy consumption. Finally, in Portugal, the approach to combating energy poverty seems less formalized. It was described in the National Energy and Climate Plan for 2019–2030, which simply states that "a long-term strategy will be developed to combat energy poverty […] to reduce energy poverty in the medium and long-term, on a national, regional, and local scale."

As regards policies to combat energy poverty, following Chlechowitz et al. (2021), we distinguish between a 'palliative' – providing short-term relief to affected households – and a 'preventive' approach, targeting the root causes of EP. While in northern European countries the issue of energy poverty tends to be assimilated with that of income poverty, the Mediterranean countries, despite their warmer climate, identify energy poverty as a distinctive area of distress to be addressed[7] with specific initiatives both to ease the stress of the burden of energy bills and to try to eradicate the problem.

With the aim of helping poor and vulnerable households, France has introduced a palliative approach with the Energy Voucher program (*Chèque énergie*), which is an annual cash transfer based on income level and household size to assist in the payment of energy bills and to help fund retrofitting investments. On average the transfer amount does not cover the estimated energy poverty gap.[8] In Greece, one of the most important policy measures is the Social Domestic Tariff, which was introduced to protect vulnerable consumers by providing discounts to those eligible (low-income households, parents with three vulnerable children, long-term unemployed, persons with disabilities and persons who require medical devices for life support at home).[9] In Italy, electricity and gas economic hardship bonuses (*Bonus energia* and *Bonus gas*) are provided for those families with an income level below a certain threshold or where one or more household members has a severe health problem.[10] Portugal, the country showing the sharpest decrease in EP, has addressed the issue of energy poverty and vulnerability through a social tariff (*Tarifas sociais*) for electricity and natural gas and a VAT reduction. As for Spain, the social tariff for electricity and natural gas (*Bono social*) has a different level of discount depending on the severity of economic and social distress of a household (ranging between 25% and 100%).[11]

The preventive approach aims at increasing household energy efficiency. According to the MURE (Mesures d'Utilisation Rationnelle de l'Énergie) database, as of 2021 only two energy efficiency policies – those of Portugal and Greece – can be considered specifically targeted to

[5] The package contains several regulatory measures – including a regulation to increase building efficiency - and a specific invitation to member countries aimed at ensuring that energy poor households are prioritized when setting energy efficiency measures.

[6] See the EU communication COM 2020 662.

[7] The importance of the energy poverty issue in some of the five Mediterranean countries is well illustrated by the existence of dedicated institutions and plans. France has its own French Energy Poverty Observatory, Greece delivered an Action Plan for the Confrontation of Energy Poverty in September 2021 to ensure the fulfilment of the specified targets within the Greek NECP, Spain has a National Strategy against Energy Poverty 2019–2024 (SNSEP) and from 2021 in Portugal a Long-Term National Strategy against Energy Poverty (2021–2050).

[8] Barella et al. (2021).

[9] See https://www.gov.gr/en/sdg/consumer-rights/connection-to-utilities/electricity/social-residential-tariff for further details

[10] Because of the low take-up rate (around 30% of the estimated households in need), since 2021 it has been fully automated. See Miniaci et al. (2014) for a discussion on eligibility criteria. Despite the existence of these two targeted programmes, an official definition of energy poverty is still lacking in Italy.

[11] For an analysis of the Bono Social, see Bagnoli and Bartomeu-Sanchez (2022).

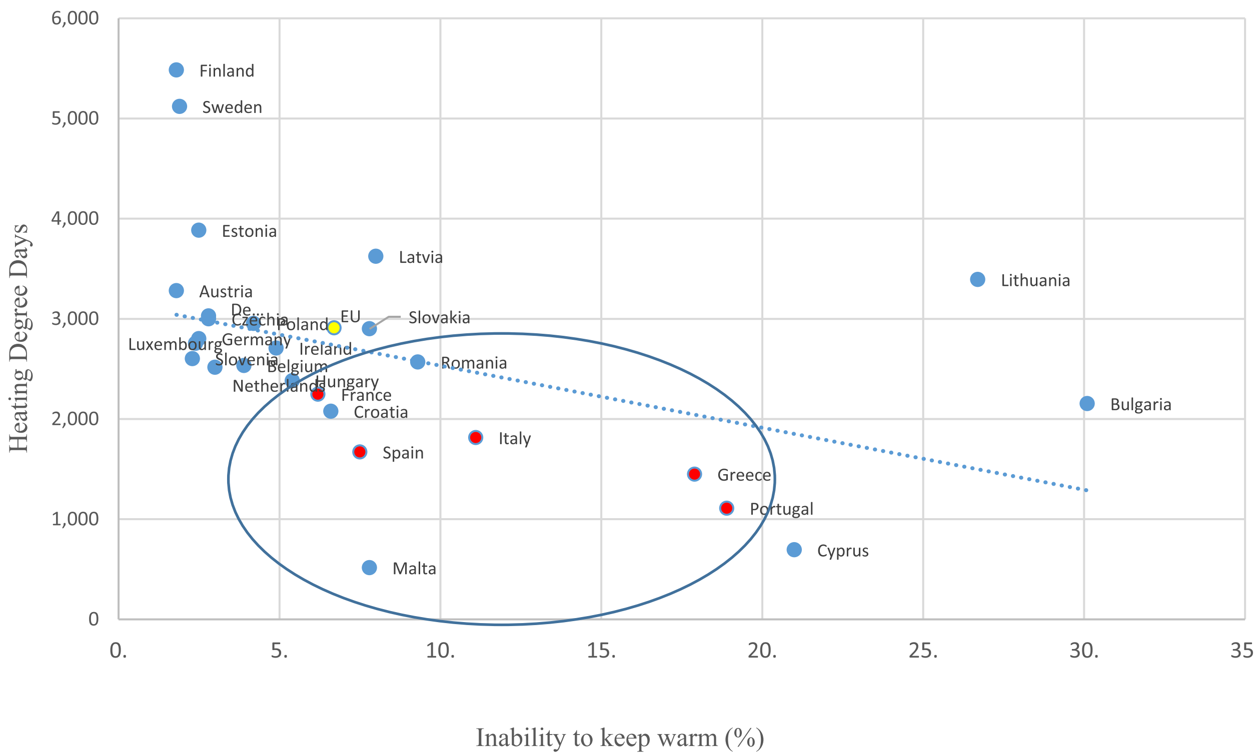

Fig. 1. Climate and inability to keep the home adequately warm in 2019.
Source: Eurostat and EU-SILC databases.

energy poor households.[12] Most measures adopted in southern Europe consist of subsidies for improving energy efficiency in buildings and not targeted exclusively to energy poor households. An example of a policy classified as partially targeted to energy poverty is the 'Program for Energy Retrofit of Existing Buildings' (PREE) in Spain, whose eligibility follows social and energy efficiency criteria. France has adopted several policy measures to achieve the energy efficiency target using different instruments – ranging from information related measures to tax incentives - and the majority have been classified by MURE as high impact measures. Finally, in Italy although a number of different policies have been adopted, only the Superbonus, a tax credit worth 110% of the eligible expenditure between 2020 and 2023 is considered to be a high-impact measure. However, since the tax credit is available for all households and for all dwellings, it is far from being focused on energy poverty.

4. Methodology: latent class analysis

Latent class methodology (LCM) allows us to assume that being in energy poverty is related to observable factors. Latent class analysis derives from the pioneering work of Lazarsfeld and Henry (1968). The latent class model is a measurement model that allows observable variables, known as manifest variables, to be related to the latent phenomenon under study, in this case energy poverty. It also enables a structural model to be implemented to characterize the distribution of the latent variable and the impact of its antecedent variables (Masyn, 2013).

Given that the methods of calculating energy poverty are still the subject of controversy and debate in Europe, the latent class method is a good candidate for measuring and studying the phenomenon without using an indicator and therefore without having any preconceived ideas of how to measure it. Both the literature and the European Commission agree that energy poverty concerns households with a combination of financial difficulties and insufficient home energy efficiency, and for whom energy expenditure represents a substantial proportion of their income. This results in difficulty paying energy bills, home heating in winter, or keeping cool in summer. We use these observable factors to conduct a latent class analysis.

Moreover, in the realm of multidimensional and clustering analysis, LCM has many advantages. One of these is related to the choice of the number of classes and measurement of distance. These choices are not subjective such as in clustering analysis (Ketchen and Shook, 1996) but based on statistical criteria (Akaike and Schwartz) and a probabilistic approach. Another advantage of LCM is the potential to deal with large datasets and obtain meaningful profiles where clustering analysis is less efficient (Ketchen and Shook, 1996).

Individuals are implicitly divided into Q classes that are not directly observable, unlike the characteristics that determine their existence. The unobserved heterogeneity justifying whether individuals are energy insecure or not varies with the observed variables and therefore justifies their belonging to one of the Q classes. The assumption of local or conditional independence implies that membership of a given class explains all the heterogeneity between classes (Masyn, 2013). The classes thus defined are assumed to be homogeneous and separate (Collins and Lanza, 2009).

A large body of literature emphasizes the need not only to consider multiple dimensions to characterize energy poverty, but also the limiting nature of a binary indicator. For this reason, we select four manifest variables to define energy poverty, and three latent classes instead of two thus identifying not only energy poor and energy sufficient households, but also energy vulnerable households.

Let $Q = 1, \ldots, q$ be the number of latent classes, and y_{it} denote the assignment to a specific class for household in situations T_i:

[12] Since 2020 the Greek "Saving-Autonomous" program provides homeowners with loans and grants for renewable energy equipment installation and is aimed at reducing the energy consumption of recipients by around 9%. Starting from 2016 in Portugal, social tariffs for electricity and gas have been implemented and targeted at energy-vulnerable households, including elderly people.

$$P_{it|q}(j) = Prob(y_{it} = j|class = q) = \frac{exp(x_{it}^{'}\beta_q)}{\sum_{j=1}^{J_i} exp(x_{it}^{'}\beta_q)} \quad (1)$$

Let the model be a logit model for discrete choice with J_i alternatives for household i, and $q = 1, .., 3$.

The probability of a household i for class q (H_{iq}) is given by a multinomial logit where z is a set of observable variables entering the model for the class membership:

$$H_{iq} = \frac{exp(z_i^{'}\theta_q)}{\sum_{q=1}^{Q} exp(z_i^{'}\theta_q)}, q = 1, .., 3, \theta_Q = 0 \quad (2)$$

The Qth parameter θ is normalized to 0 to guarantee the identification (Greene and Hensher, 2003).

The joint probability of $y_i = (y_{i1}, \ldots, y_{iT})$ gives the contribution of household i to the likelihood:

$$P_{i|q} = \prod_{t=1}^{T_i} P_{it|q} \quad (3)$$

The likelihood for individual i and the log-likelihood are then:

$$P_i = \sum_{q=1}^{Q} H_{iq} P_{i|q} \quad (4)$$

$$lnL = \sum_{i=1}^{N} lnP_i = \sum_{i=1}^{N} ln\lceil \sum_{i=1}^{Q} H_{iq} \left(\prod_{t=1}^{T_i} P_{it|q} \right) \rceil \quad (5)$$

The estimated choice probabilities give the household-specific estimate of the class probability, which is given by $\widehat{H_{q|i}}$. The empirical estimator of the latent class to which the household belongs is associated with the maximum value of the probabilities obtained for the classes. Using the Bayes theorem, we obtain the posterior estimate of the latent class probabilities:

$$\widehat{H_{q|i}} = \frac{\widehat{P}_{i|q}\widehat{H}_{i|q}}{\sum_{q=1}^{Q} \widehat{P}_{i|q}\widehat{H}_{i|q}} \quad (6)$$

The parameter vector for each observation is then obtained as follows:

$$\widehat{\beta}_i = \sum_{q=1}^{Q} \widehat{H}_{i|q}\widehat{\beta}_q \quad (7)$$

After characterizing the probabilities of households belonging to the different latent classes in the measurement model, we introduce covariates, representing the attributes of the household, which affect the probability of belonging to these classes. For this purpose, a structural model is constructed. The covariates are introduced via a multinomial logit model. The regression coefficients indicate the effect of a one-unit increase in the n*th* covariate on the probability of belonging to class q compared to the reference class.

5. Data and variables

5.1. The EU survey of income and living conditions (EU-SILC)

Our objective is to highlight evidence of classes of households exposed to vulnerability or even energy poverty in five southern European countries. We have chosen these countries as they share a number of very similar characteristics including climate and energy-efficiency features of their homes. Their climate is warmer in summer and milder n winter compared with the rest of Europe, but housing often appears to be less energy efficient (Attia et al., 2017). Despite the limitations outlined above, the EU-SILC is the best database to use for conducting the desired latent class analysis using several qualitative indicators of exposure to energy poverty and vulnerability, and also to make comparisons between European countries. We selected cross-sectional data from 2019 for Greece, Spain, France, Italy and Portugal. The final sample contains 79,629 observations for the five countries. Some comparisons have been made with the year 2008 containing 55,139 observations.

For our model, we selected variables in the EU-SILC database commonly used in micro-level cross-country comparisons to study the phenomenon (Dubois and Meier, 2016; Thomson and Snell, 2013) and recommended by the European Commission (2020). Indeed, the use of several indicators is suggested to capture the multidimensional aspects of this type of deprivation. Using latent class methodology, we can define three classes (Eqs. 1 and 2), energy sufficient households, vulnerable households, and the energy poor, by simultaneously using four variables available in the EU-SILC database: a leaking roof, damp walls or rotten window frames, inability to adequately heat one's dwelling in winter, difficulty making ends meet and a heavy financial burden linked to housing costs.

The European Commission adopts a very broad definition of fuel poverty compatible with different national approaches, but nevertheless stresses that fuel poverty is based on the following attributes: energy expenditure in relation to income, inability to satisfy basic energy needs, inadequacy of housing conditions, having arrears on utility bills, and the inability to keep one's home adequately warm or cool (European Commission, 2020). We have therefore selected the EU SILC survey variables compatible with these criteria.

The presence of leaks and difficulty heating the dwelling are two indicators of energy efficiency while difficulty making ends meet, financial burden of the housing, or even difficulty heating the home are three indicators indirectly linked to income and prices. The inability to keep the home adequately warm is an outcome of energy poverty that should be coupled with other indicators to bridge the gap between causes and effects (Gouveia et al., 2022). Therefore, combining this information with other variables such as housing conditions and a heavy financial burden linked to housing can provide insights on the causes of energy poverty and give a more accurate representation of the problem (Bouzarovski, 2014; Castaño-Rosa et al., 2019).

Finally, in the structural model we selected some covariates that affect the probability of being in one of the classes. Following the literature on energy poverty, household-specific characteristics are considered (age of the oldest person in the household, equivalized disposable income, health status, housing tenure and household size).[13] Age is a key factor, because in some countries, older people who no longer have any income from work, but who have to bear the heavy costs of maintaining their homes, are more exposed to the risk of energy poverty (Legendre and Ricci, 2015). These maintenance costs and bill payments are also closely linked to the occupancy status of the home (Charlier and Legendre, 2021). Standard of living is obviously a decisive variable that protects against exposure to fuel poverty (Sánchez-Guevara et al., 2015), even more so in the case of large families. Finally, a large body of recent literature has also developed on the close link between health and fuel poverty (Charlier and Legendre, 2022).

We also examine the residential location (urban, peri-urban or rural area) and the type of building to infer the potential need for heating (detached house, semi-detached house or apartment in a multi-family building). Fig. 2 lists the four manifest variables on the right and the covariates of the structural model on the left.

5.2. Descriptive statistics

Table 1 summarizes some descriptive statistics for the year 2019 for

[13] Disposable income is equivalized using the square root of household size as an equivalence scale (as suggested by OECD). The dummy of poor health status is equal to 1 if there is at least one family member reporting their health is poor or very poor.

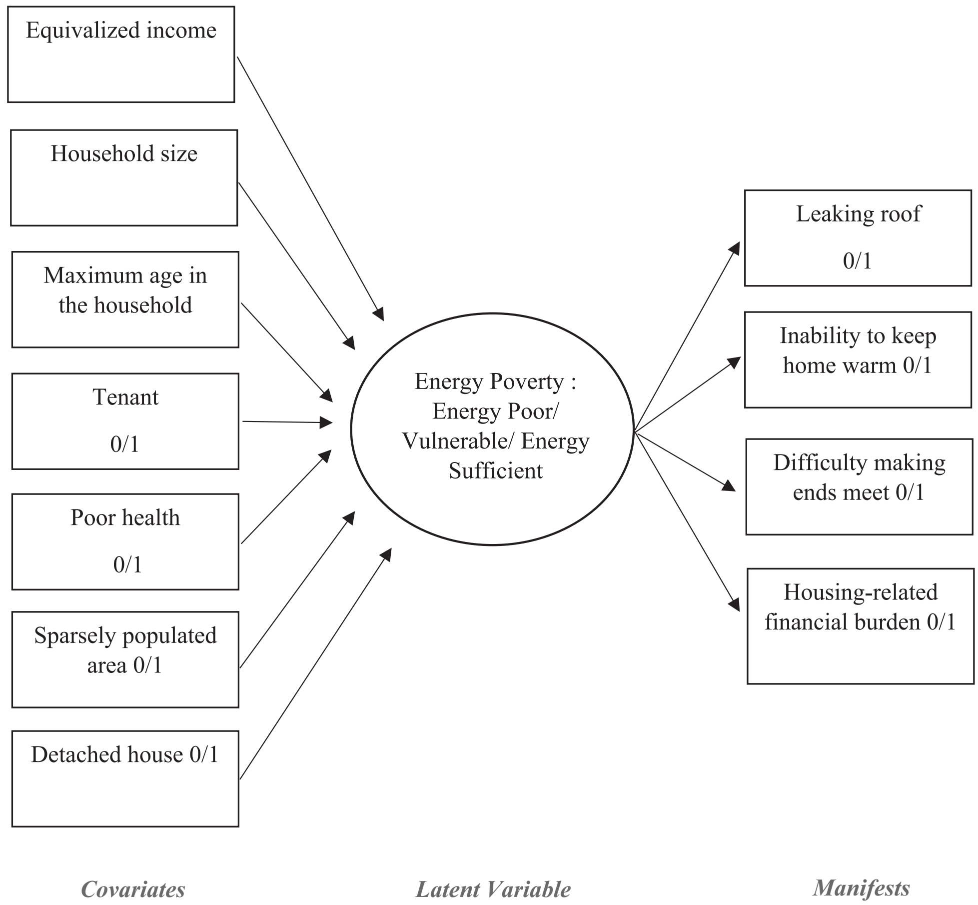

Fig. 2. Path diagram: measurement and structural model of energy poverty.

the European countries studied here. Looking at the national indicators used as manifest variables of energy poverty, most Mediterranean countries have on average between 11 and 15% poor housing conditions. However, the share is higher in Portugal (24%). In Spain, France and Italy, the share of households unable to keep their home adequately warm ranges between 7 and 12% on average, with Greece and Portugal showing much higher statistics (18 and 20%, respectively). A strong heterogeneity also exists in the difficulty of making ends meet. While 58% of households suffer from this problem in Spain, 90% of households are affected in Greece. In all countries, the burden of housing expenditure is a significant problem except in France, where the magnitude is much lower. The correlation matrices between the manifest variables for each Mediterranean country are presented in Table 2. We observe that the correlation parameters are not too high, which tends to show that each manifest variable has a distinct role in classifying households.

Regarding the variables used in the multinomial logit, as expected the standard of living is not homogenous in the selected countries. In 2019, the average equivalized income ranges from 16,242 euros in Greece to 39,686 euros in France. Household demographic characteristics are more similar: the average maximum age ranges between 55 years in France and over 59 in Greece and Italy. The maximum age within the household does not necessarily translate into poorer health,

Table 1
Descriptive statistics for selected Mediterranean countries, 2019.

	Greece	Spain	France	Italy	Portugal
Manifest variables					
Leaking roof	13%	15%	11%	14%	24%
Unable to keep home adequately warm	18%	8%	7%	12%	20%
Great difficulty making ends meet	90%	48%	56%	60%	63%
Housing-related financial burden	96%	95%	45%	98%	80%
Covariates					
Equivalized Income	16,242	29,203	39,686	31,451	19,689
Household size	2.55	2.50	2.14	2.31	2.46
Poor health	13%	13%	14%	15%	26%
Max age	59.82	57.72	55.52	59.42	58.98
Sparsely pop. Area	31%	26%	34%	17%	26%
Tenant	22%	15%	21%	19%	14%
Detached house	31%	13%	38%	22%	36%
Observations	17,829	15,804	11,656	20,787	13,553

Table 2
Correlation matrix for manifest variables, 2019.

	Leaking roof	Unable to keep home adequately warm	Great difficulty making ends meet	Housing-related financial burden
		Greece		
Leaking roof	1.0000			
Unable to keep home adequately warm	0.1389	1.0000		
Great difficulty making ends meet	0.0501	0.1380	1.0000	
Housing-related financial burden	0.0308	0.0664	0.2821	1.0000
		Spain		
Leaking roof	1.0000			
Unable to keep home adequately warm	0.1435	1.0000		
Great difficulty making ends meet	0.1452	0.2484	1.0000	
Housing-related financial burden	0.0257	0.0379	0.1556	1.0000
		France		
Leaking roof	1.0000			
Unable to keep home adequately warm	0.1831	1.0000		
Great difficulty making ends meet	0.1416	0.2069	1.0000	
Housing-related financial burden	0.1173	0.2142	0.4707	1.0000
		Italy		
Leaking roof	1.0000			
Unable to keep home adequately warm	0.1267	1.0000		
Great difficulty making ends meet	0.1220	0.2177	1.0000	
Housing-related financial burden	0.0256	0.0146	0.0857	1.0000
		Portugal		
Leaking roof	1.0000			
Unable to keep home adequately warm	0.1669	1.0000		
Great difficulty making ends meet	0.1583	0.2493	1.0000	
Housing-related financial burden	0.0761	0.1591	0.4266	1.0000

since 26% of Portuguese respondents report poor health with an average maximum age of 59 years, while only 13% of Greek households report poor health. Finally, homeowners make up a larger share of the population in the Iberian Peninsula, while the share of tenants is around 20% in the other countries. The standard housing also differs between countries, since in France, almost 38% of households live in detached houses, while in Spain only 13% do, and in Italy 22%. Roughly the same proportions are observed in urban or rural areas.

6. Results

6.1. Magnitude of energy poverty and energy vulnerability in each country

The model enables us to identify three different classes, thus providing evidence of a large group of energy vulnerable households (class 2).[14]According to the results (Table 3), we can see that Class 1 identifies energy sufficient households, Class 2 energy vulnerable households, and Class 3 energy poor households. Indeed, in Class 1, we have a smaller share of households with difficulty heating their homes, problems with poor housing conditions, making ends meet or with housing-related financial burdens compared with households in Class 3. These results are consistent across all countries. What is interesting is that by avoiding binary logic, a third category (class 2) emerges as does a profile of vulnerable households, which have intermediate characteristics between those who could be classified as energy poor and those who could be considered non-energy poor. They are therefore in a situation of potential energy vulnerability being much more likely to have housing-related financial burdens and difficulty making ends meet compared with the non-energy poor in class 1.

Then, looking at the percentage of the population distributed in each class in 2019 (Table 4), the share of units in Class 1 (energy sufficient households) is quite heterogeneous across countries, being 12.9% in Greece, but 51.8% in Spain. The share of energy poor households varies between 24.3% in Portugal and 6.6% in Spain. Greece and Spain are the two countries with the highest share of energy poverty as defined by the four manifest variables. Moreover, households classified as energy poor possess at least three of the four dimensions (manifest variables) on average and as one would expect, the non-poor face almost none of these problems.

As a robustness check of our results, we ran the same model for the year 2008, which was before the European economic crisis resulting from the turmoil on the financial markets which began in the United States, and the EU sovereign debt crisis. Our results comparing the years 2008 and 2019 are consistent (Table 4) so the general structure identified using our LCA model appears stable and time consistent. While the share of poor households decreased between 2008 and 2019 in all countries, this is not necessarily the case for the share of vulnerable households. For example, energy poor represented 13.5% of Italian households in 2008 and this dropped to 7.3% in 2019. A similar trend is observed in Spain where this share decreased from 10.0 to 6.6%. On the other hand, the share of vulnerable households increased from 52.5 to 64.25% in Greece and from 62.3 to 50.5% in Italy and was stable in Portugal at around 40%.

However, the depth of energy poverty worsened over time, as the number of conditions for being considered energy poor increased on average for all countries between the two periods. For example, in France, households in Class 3 – the energy poor - experienced an average of 3.05 difficulties of the four manifest variables in 2008 while they faced greater difficulties — 3.12 – in 2019. In Spain this increased from 3.05 in 2008 to 3.30 in 2019. In summary, households in energy poverty decreased in 2019 across the five countries, but the conditions of those considered to be in energy poverty (belonging to Class 3) certainly

[14] To define the number of classes, we compare models including two and three latent classes using AIC and BIC criteria ((Goodman, 2002)Smaller AIC and BIC values are better. We prefer a model with three classes as the three-class model has the smallest AIC and BIC values, and this is confirmed for each country. Results of the tests are presented in Table A in the Appendix.

Table 3
Main results by country (2019).

	Greece			Spain			France			Italy			Portugal		
	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
0. Roof does not leak	92.45	92.10	71.83	91.75	83.98	61.26	94.26	89.61	63.03	92.07	85.00	63.99	83.96	78.78	51.67
1. Leaking roof	7.55	7.90	28.17	8.25	16.02	38.74	5.74	10.39	36.97	7.93	15.00	36.01	16.04	21.22	48.33
0. Able to keep home adequately warm	98.41	92.14	50.27	99.20	94.76	38.04	99.29	97.53	49.66	98.39	91.46	30.69	95.91	93.12	45.26
1. Unable to keep home adequately warm	1.59	7.86	49.73	0.80	5.24	61.96	0.71	2.47	50.34	1.61	8.54	69.31	4.09	6.88	54.74
0. No difficulty making ends meet	60.09	0.00	0.81	94.43	14.51	2.35	92.44	4.11	2.53	82.17	0.00	4.53	94.64	13.03	3.38
1. Great difficulty making ends meet	39.91	100.00	99.19	5.57	85.49	97.65	7.56	95.89	97.47	17.83	100.00	95.47	5.36	86.97	96.62
0. No Housing-related financial burden	17.66	0.51	0.99	7.97	0.33	1.76	83.29	36.99	10.16	2.86	0.27	1.19	48.58	6.98	3.59
1. Housing-related financial burden	82.34	99.49	99.01	92.03	99.67	98.24	16.71	63.01	89.84	97.14	99.73	98.81	51.42	93.02	96.41

Table 4
Share of households by class.

		Greece		Spain		France		Italy		Portugal	
		2008	2019	2008	2019	2008	2019	2008	2019	2008	2019
Class 1	%	17.61	12.81	39.51	51.81	45.29	44.23	24.12	42.12	17.19	34.78
	Number of manifests[a]	0.91	1.03	1.04	1.03	0.38	0.26	1.12	1.11	0.62	0.75
Class 2	%	52.51	64.25	50.42	41.58	45.73	47.72	62.39	50.56	40.04	40.95
	Number of manifests	2.05	2.10	2.14	2.17	1.80	1.73	2.17	2.22	1.99	2.07
Class 3	%	29.88	22.94	10.07	6.62	8.98	8.05	13.49	7.32	42.77	24.27
	Number of manifests	2.91	3.02	3.05	3.30	3.05	3.12	3.31	3.36	3.07	3.20

[a] We have calculated the average number of manifest variables by class that households meet.

deteriorated.

6.2. *Profiles in each of the classes*

6.2.1. *Energy poverty and energy vulnerability features: What the manifest variables tell us*

While the difference between energy sufficient and vulnerable households does not appear to be particularly marked according to the energy poverty criteria in the manifest variables, a divergence emerges between the energy poor and other classes (Table 3). This is particularly the case for the variables directly linked to the energy efficiency of the dwelling. Thus Class 3, the energy poor, suffer more frequently from poor housing conditions and find it very difficult to heat their homes. In the selected countries, between 6 (France) and 16% (Portugal) of the energy sufficient have poor housing while this condition characterizes 48% of the energy poor in Portugal and 39% in Spain. At least half of the energy poor (Class 3) report they are unable to adequately heat their homes in winter. This figure is 50% in Greece and France, and 69% in Italy. This appears to be much less frequent among the energy sufficient and the vulnerable, <10% of whom report difficulties in keeping their homes warm enough. In Italy, 2% of the energy sufficient and 9% of the vulnerable households report this inability. In Spain, the figures are 1 and 5% respectively.

The results are more heterogeneous for the other two manifest variables. In the case of Greece, among the energy sufficient, 40% report difficulty making ends meet, with 100% of the vulnerable and 99% of the energy poor reporting difficulty making ends meet. In Portugal and Spain, these difficulties are more progressive between the classes: respectively 5 and 6% of the energy sufficient population report difficulty making ends meet. In contrast, 97 and 98% of those in energy poverty do so.

In Greece, Spain and Italy, housing expenses represent a financial burden that the population overwhelmingly considers to be extremely heavy. In Italy and Spain, >90% even of the energy sufficient find this financial burden very heavy and obviously the share is greater among the energy poor. Conversely, for most energy sufficient French households (17%), the burden of housing-related expenses does not represent a challenge, while the share rises to 63% among the vulnerable and 90% for the energy poor.

6.2.2. *Class membership drivers*

The covariates allow us to identify the attributes of membership of Classes 2 and 3, i.e., the energy vulnerable and energy insecure classes (Table 5, see Table A in the appendix for estimated coefficients).[15] Four characteristics are common to the energy vulnerable and energy poor in the five countries: an increasing equivalized income reduces the probability of being in the energy vulnerable and energy poor classes rather than in the energy sufficient class. While income is a protective factor against energy poverty, household size increases the risk of being in Classes 2 and 3. This is also the case when the head of the household reports being in poor health or when the household is in private rental stock. The effect of age is very different across countries as it is linked to the characteristics of the national welfare states and to intergenerational inequality. In Greece and France, for example, older age increases the risk of belonging to the precarious and vulnerable classes. Conversely, in Spain, this risk decreases as age increases and in Italy age has no influence on the probability of belonging to the classes. The type of housing also affects class membership. In Greece and Italy, living in detached houses increases the probability of belonging to Classes 2 and 3. In France, on the other hand, it has the opposite effect. In other words, the energy sufficient often live in detached houses.

7. Discussion: understanding the energy vulnerability

The households categorized into the three classes using the latent class model can be further analyzed with some additional dimensions. This approach to exploring other dimensions of precariousness is inseparable from energy poverty or energy vulnerability. Indeed, recent work by the European Commission's Energy Poverty Advisory Hub emphasizes the need for a comprehensive approach. This implies formulating policies that consider the various causes of fuel poverty: poor quality of buildings, poor energy performance, socio-economic factors, and degraded thermal comfort.

In particular, it is interesting to distinguish the vulnerable households from those who can definitely be considered energy poor. Indeed, those vulnerable to energy poverty represent a non-negligible share of

[15] Class 1, i.e., the energy sufficient class, is used as a reference.

Table 5
Effects of covariates on the probability of being in each class (2008 and 2019).

	Greece				Spain				France				Italy				Portugal			
	Class 2		Class 3		Class 2		Class 3		Class 2		Class 3		Class 2		Class 3		Class 2		Class 3	
	2008	2019	2008	2019	2008	2019	2008	2019	2008	2019	2008	2019	2008	2019	2008	2019	2008	2019	2008	2019
Equivalized. income	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Household size	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	ns	+	+	+	+
Max age within the household	–	ns	+	+	–	ns	–	–	+	+	+	+	ns	ns	ns	ns	–	ns	–	+
Poor health	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Tenant	+	+	+	+	+	+	+	+	ns	+	+	+	+	+	+	+	ns	+	+	+
Sparsely pop. Area	–	ns	–	–	–	–	ns	ns	ns	+	+	ns	–	ns	–	–	ns	ns	–	–
Detached house	ns	ns	+	+	–	ns	+	ns	–	–	–	–	–	+	+	+	ns	–	ns	+
Obs	6481	17,829	6481	17,829	12,981	15,804	12,981	15,804	10,336	11,656	10,336	11,656	20,862	20,787	20,862	20,787	4451	13,553	4451	13,553

each country's total population ranging from 40% in Portugal to 64% in Greece. Therefore, a deeper understanding of their difficulties is crucial to formulating effective policies. In Fig. 3, we compare these groups along selected characteristics and thus address the need for more comprehensive information, identifying energy insecurity or vulnerability in a broader socio-economic context.

We focus on the burden of persistent economic stress (arrears on utility bills and on mortgage and rent payments), sensitivity to unpredicted monetary costs (ability to fund unexpected expenses) and the feasibility of engaging in non-essential activities, such as leisure activities and social gatherings.[16]

Visual inspection of the radar charts shows that in both vulnerable and energy poor households the distinguishing characteristics are self-restraint in leisure activities and the inability to fund unexpected expenses. While the problem of arrears in utility bills and mortgage/rent payments is not very severe in France, Italy and Portugal, significant difficulties with these expenses are observed for both groups in Spain and particularly in Greece. Moreover, an interesting picture emerges when comparing the shapes for both groups in each country graph. In Greece and Spain, the shapes are similar for vulnerable and energy poor households, suggesting that they share the same disadvantages. In the other countries vulnerable families apparently have fewer difficulties with social activities with respect to the energy poor. However, vulnerable families in all countries - even if they manage to pay their bills and afford a certain level of social activity – can find it difficult to fund unexpected expenses. Linked to social activities and leisure is the availability of private transport which is an important asset in Mediterranean countries. Indeed, private cars are widely distributed among energy sufficient and vulnerable households with the partial exception of the vulnerable group in Greece (Table 6).

Finally, Table 6 provides further evidence of the partial overlap between energy poverty and economic poverty. For each of the five countries, we cross the relative poverty indicator – having an equivalent income below 60% of the national median – and car ownership according to the three classes of households identified with the latent class analysis. For instance, in France about half of energy poor households are also monetary poor (3.87 out of 8.19%) and only one fifth cannot afford a car (1.47%). This is the case even more so in the second class where, in all countries, most of the vulnerable households have an equivalent income above the threshold and can afford a car.

The profile of households in each class is summarized in Table 7 below.

The results suggest the need to consider policies to combat energy poverty and its consequences. When we look at the poorest category, we see that the energy poor are also poor in a more general sense and that monetary poor frequently experience different manifestations of energy poverty (Table 8).

The poorest category generally cannot afford cars (a problem of transport insecurity), live in rural areas and often are renters. For these households, income-based policies may make sense even if some households are excluded as they are not all monetary poor. In the context of a crisis where energy prices sharply increase, these households probably do not have the capacity to invest in their housing (i.e., energy efficiency measures), and barriers related to their housing tenure may also emerge. These households are frequently in a situation of exclusion, and future work could examine how the absence of a vehicle can reinforce this phenomenon especially for those in rural areas.

Moreover, with the emergence of the vulnerable class, it is possible for governments to formulate policies to prevent energy poverty. In this class, the energy vulnerable are not necessarily monetary poor and policies based solely on this criterion may be ineffective insofar as some households will not be affected by the measures. Vulnerable households are often renters. They are unlikely to invest in energy efficiency measures. We know that health problems reinforce membership in this class, so special attention must be paid to such households to help prevent additional expenses related to poor housing and energy deprivation in the context of increasing prices. Incentives for landlords to improve the energy efficiency of housing would help households save on their energy bills. This would also prevent future health problems and the associated social welfare costs.

The literature on fuel poverty in Europe clearly shows that preventive measures to improve the energy efficiency of housing are the only way to combat fuel poverty effectively and sustainably. The five countries studied here have effectively implemented this type of policy (e.g., PREE in Spain, Superbonus in Italy etc.). However, the measures rarely target energy poor households alone. Vulnerable households, who are often not monetary poor, are even less targeted by means-tested public policies. So even if these measures do help to improve the energy efficiency of the housing stock, as in Italy with the Superbonus, or in France with tax breaks, this type of policy does not specifically target households in need. Furthermore, the energy poor and energy vulnerable households are systematically excluded when they are unable to fund energy efficiency renovations, or to spend the required funds to qualify for a tax deduction for example. Yet our results show that in the five countries, energy poor and vulnerable households are unable to meet unexpected expenses (Fig. 3). Consequently, considerable resources are devoted to different retrofitting policies, but they neglect the populations most in need. Better targeting of this population would therefore be key to simultaneously combating energy inefficiency in housing and the resulting precariousness. Generally speaking, the energy poor and vulnerable suffer from various forms of exclusion, as Fig. 3 shows. This has many consequences beyond energy and finances, and access to information can also be difficult. This is why information campaigns about available programs and funding and what steps to take could be of

[16] The two questions in the EU-SILC survey are: "Do you get together with friends/family (relatives) for a drink/meal at least once a month?" and "Do you regularly participate in a leisure activity (that costs money)?".

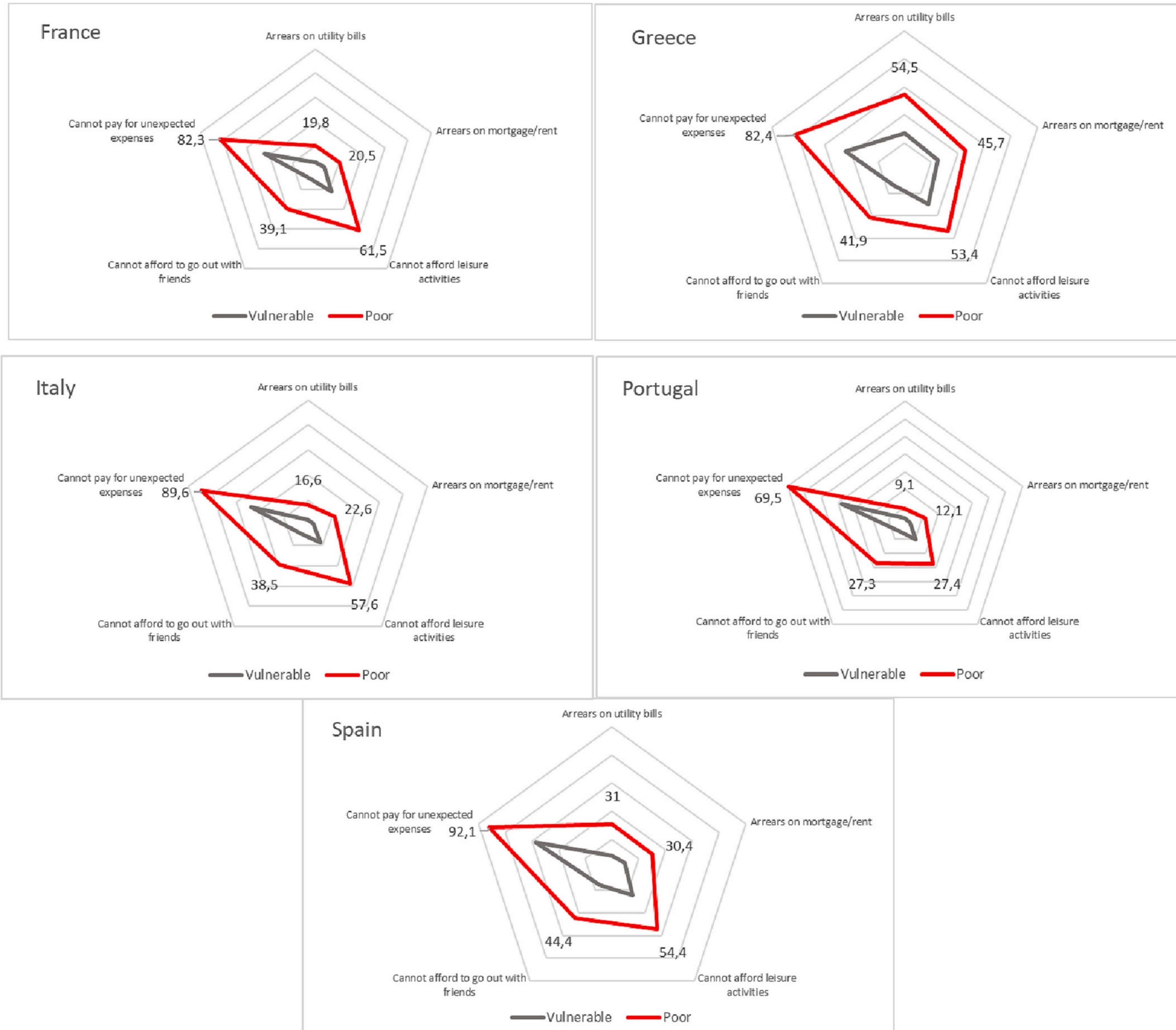

Fig. 3. Selected characteristics of vulnerable and energy poor in Mediterranean countries (2019).

great help in supporting vulnerable households.

When subsidies are available, other difficulties can arise on the supply side. For example, some renovation companies may become rent-seekers, raising their prices when they know that bonuses are available. An innovative policy could be to encourage governments to develop networks of approved professionals for renovation work. Particular attention should be paid to the quality of the professionals selected, and to their tariffs, to prevent unscrupulous professionals from benefiting from renovation incentives and subsidies through rent-capture systems, for example. This kind of good practice would go some way to remedying what appears to be a major problem for which few governments have found a solution.

8. Conclusions

In this paper, by providing a tool for identifying a scale of energy poverty, we identify a new class: the energy vulnerable. Particular attention is paid to Mediterranean countries often characterized by poorly insulated homes with a non-negligible share of dwellings still lacking satisfactory heating systems or any heating system at all. All these countries share high income inequality indexes and high energy prices, linked to an almost complete traditional energy dependency (nearly non-existent fossil fuel resources). Using a latent class analysis method, we overcome the dichotomous characterization of energy poverty to also consider those groups at risk of falling into energy poverty in the future due to vulnerability factors. As we demonstrate here, the advantage of this method is the potential to characterize national profiles over time with a single tool. This allows the same method to be replicated over time and across countries, and thus allows international comparisons to be made.

Based on the four observable criteria used by the European Commission to characterize energy and monetary poverty (leaking roof, difficulty heating the dwelling properly, housing-related financial burden and difficulty making ends meet), we show that 6.62% of the population is energy poor in Spain, reaching 24.27% in Portugal. Between these two extremes, Italy has an energy poverty rate of 7.32%, France 8.05% and Greece 22.94%. In contrast, only a very small proportion (12.81%) of the population appears to be energy sufficient in Greece, while this share rises to 51.81% for the Iberian Peninsula.

The use of latent class methodology establishes that distinguishing

Table 6
Monetary poverty vs energy poverty (%).

Energy poor		Non poor	Vulnerable	Poor	
FRANCE					
Monetary poor	No	42.27	39.75	4.32	86.34
	Yes	1.8	7.99	3.87	13.66
Have a car	Yes	38.83	39.04	5.54	83.41
	Not, cannot afford	0.28	2.49	1.47	4.24
	No, other reason	4.98	6.2	1.18	12.35
	total	44.08	47.73	8.19	100
GREECE					
Monetary poor	No	12.49	57.17	13.84	83.49
	Yes	0.32	7.09	9.09	16.51
Have a car	Yes	10.94	49.35	11.14	71.43
	Not, cannot afford	0.42	5.49	4.78	10.69
	No, other reason	1.45	9.42	7.02	17.88
	total	12.81	64.25	22.94	100
ITALY					
Monetary poor	No	38.57	38.62	2.68	79.87
	Yes	3.55	11.95	4.63	20.13
Have a car	Yes	36.82	39.36	3.85	80.02
	Not, cannot afford	0.11	1.3	1.06	2.47
	No, other reason	5.19	9.91	2.4	17.5
	total	42.12	50.56	7.32	100
PORTUGAL					
Monetary poor	No	33.12	34.94	13.62	81.68
	Yes	1.74	5.96	10.63	18.32
Have a car	Yes	30.41	33.81	14.05	78.28
	Not, cannot afford	0.36	1.73	4.13	6.23
	No, other reason	4.09	5.35	6.06	15.49
	total	34.86	40.89	24.25	100
SPAIN					
Monetary poor	No	47.34	30.65	2.66	80.65
	Yes	4.45	10.91	3.99	19.35
Have a car	Yes	43.6	30.87	3.71	78.18
	Not, cannot afford	0.63	2.78	1.38	4.79
	No, other reason	7.71	7.82	1.5	17.03
	total	51.94	41.47	6.59	100

Source: Authors' elaborations.

three classes rather than two is statistically relevant. In other words, the model validates the statistical existence of a third class, which we know exists, halfway between the poorest exposed to energy poverty, and this small portion of the population that has no difficulty in affording the energy services it needs. This third class identifies the energy vulnerable requiring the full attention of public authorities as this class is often overlooked by policies, but they can fall into the energy poor class at the slightest unanticipated shock. This intermediate class accounts for a large share of the population representing 64.25% in Greece, 41.58% in Spain, 47.72% in France, 50.56% in Italy and 40.95% in Portugal in 2019. Finally, identifying a vulnerable class enables policy makers to formulate economic policy tools adapted to household profiles. We know that 40% of these households are above the poverty line (thus not targeted by a number of policies to support purchasing power), and that half of them say they are not able to fund unexpected expenses. Among these, 20% do not participate in leisure activities.

Finally, based on analysis of the 2008 data, we have shown that energy poverty has decreased in the countries in our sample, a sign that this issue is now at the forefront in conjunction with the objectives of energy and ecological transition. Nevertheless, it is worrying that despite this decline, the depth of the phenomenon for the households concerned seems to have worsened. Moreover, the proportion of vulnerable people has not necessarily declined. For example, the energy poor represented 13.5% of Italian households in 2008 dropping to 7.3% in 2019. The share of vulnerable increased from 52.5 to 64.25% in Greece.

If policies at the national level in Europe do not move forward in a coordinated way to tackle energy poverty, the European guidelines are a first step. Research ideally complements policy initiatives. This paper thus makes it possible to offer a first coordinated vision of energy poverty and vulnerability among five European countries over a decade. The next step is therefore to expand the use of these research tools to other countries, and then to use these results to advance public policies

Table 7
Profiling the three classes.

Energy sufficient	Vulnerable	Energy poor
Range between 5% (Greece) and 52% (Spain) of total population	Represent a large share of total population (between 40% in Portugal and 64% in Greece)	Represent the smallest share of total population (between 7% in Spain and 24% in Portugal)
Own a car, no difficulty with utility bills, mortgage and rent payments	Own a car, cope with utility bills, rent and mortgages	Have difficulties in coping with utility bills, rent and mortgages. Almost half of them do not own a car
Largely participate in social and leisure activities, if not, it is for reasons different from affordability	On average 20% cannot afford leisure activities but generally socialize	Show signs of social exclusion
Can afford unexpected expenses	Half have no capacity to cope with unexpected expenses	For the most part cannot fund unexpected expenses
On average 5% are below the poverty threshold	On average 40% are above the poverty threshold	A non-negligible share is above the poverty threshold in Greece and Portugal

Source: Authors' elaborations.

Table 8
Energy poverty and monetary poverty.

	Leaking roof	Able to keep home adequately warm	Great difficulty making ends meet	Housing-related financial burden
Greece				
Non poor	13%	83%	89%	96%
Monetary poor	20%	66%	98%	98%
Spain				
Non poor	13%	95%	41%	95%
Monetary poor	21%	81%	74%	97%
France				
Non poor	10%	95%	52%	42%
Monetary poor	20%	80%	85%	66%
Italy				
Non poor	12%	93%	52%	98%
Monetary poor	15%	79%	78%	98%
Portugal				
Non poor	25%	84%	60%	79%
Monetary poor	38%	64%	87%	90%

in a coordinated and effective way in order not only to combat inequality in access to energy services, but also to improve well-being and advance the energy transition.

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CRediT authorship contribution statement

Rossella Bardazzi: Conceptualization, Methodology, Software, Visualization, Investigation, Writing – review & editing. **Dorothée Charlier:** Conceptualization, Methodology, Software, Visualization, Investigation, Writing – review & editing. **Berangère Legendre:** Conceptualization, Methodology, Software, Visualization, Investigation, Writing – review & editing. **Maria Grazia Pazienza:** Conceptualization, Methodology, Software, Visualization, Investigation, Writing – review & editing.

Appendix A. AIC and BIC criterion for each country

	AIC	BIC
GREECE		
Two class model	44,894.27	45,018.88
Three class model	44,001	44,219.08
SPAIN		
Two class model	43,936.92	44,059.61
Three class model	43,477.3	43,692
FRANCE		
Two class model	39,761.71	39,879.53
Three class model	39,228.54	39,434.72
ITALY		
Two class model	55,984.52	56,111.6
Three class model	55,633.34	55,855.72
PORTUGAL		
Two class model	52,935.09	53,055.32
Three class model	52,171.81	52,382.21

Appendix B. Impact of covariates on class membership

	Class 2 (ref class 1)			Class 3 (ref class 1)		
	coeff	std error	sig	coeff	std error	sig
			Greece (Obs = 17,829)			
Equivalized income	−0.0002	0.0000	***	−0.0005	0.0000	***
Household size	0.2801	0.0322	***	0.1956	0.0450	***
Max age within the household	−0.0013	0.0026		0.0168	0.0037	***
Poor health	0.2947	0.1301	**	1.5372	0.1437	***
Tenant	0.3446	0.1260	**	1.3015	0.1574	***
Sparsely pop. Area	0.0451	0.0836		−0.3702	0.1147	***
Detached house	0.1010	0.0834		0.3733	0.1102	***
			Spain (Obs = 15,804)			
Equivalized income	−0.0001	0.0000	***	−0.0002	0.0000	***
Household size	0.2021	0.0213	***	0.2183	0.0578	***
Max age within the household	−0.0011	0.0019		−0.0079	0.0039	**
Poor health	0.8057	0.0923	***	2.0655	0.1850	***
Tenant	0.5957	0.0982	***	1.5617	0.1430	***
Sparsely pop. Area	−0.1809	0.0551	***	−0.1717	0.1166	
Detached house	−0.0225	0.0764		−0.0990	0.1630	
			France (Obs = 11,656)			
Equivalized income	−0.0001	0.0000	***	−0.0002	0.0000	***
Household size	0.2217	0.0266	***	0.2092	0.0523	***
Max age within the household	0.0084	0.0019	***	0.0132	0.0034	***
Poor health	0.5804	0.0852	***	1.3081	0.1407	***
Tenant	0.2008	0.0821	**	0.9079	0.1408	***
Sparsely pop. Area	0.1290	0.0597	**	0.1553	0.1227	
Detached house	−0.1210	0.0619	*	−0.3742	0.1410	**
			Italy (Obs = 20,787)			
Equivalized income	−0.0001	0.0000	***	−0.0002	0.0000	***
Household size	0.1356	0.0196	***	0.0450	0.0503	
Max age within the household	0.0014	0.0015		−0.0002	0.0040	
Poor health	0.7250	0.1166	***	2.0411	0.1822	***
Tenant	0.9071	0.0676	***	1.6020	0.1369	***
Sparsely pop. Area	0.0140	0.0515		−0.6599	0.1661	***
Detached house	0.1765	0.0489	***	0.4072	0.1264	***
			Portugal (Obs = 13,553)			
Equivalized income	−0.0001	0.0000	***	−0.0003	0.0000	***
Household size	0.3093	0.0342	***	0.3524	0.0422	***

(continued on next page)

(*continued*)

	Class 2 (ref class 1)			Class 3 (ref class 1)		
	coeff	std error	sig	coeff	std error	sig
Max age within the household	−0.0040	0.0027		0.0077	0.0032	**
Poor health	0.5429	0.0920	***	1.4230	0.1058	***
Tenant	0.3621	0.1198	**	1.0962	0.1256	***
Sparsely pop. Area	0.0232	0.0701		−0.4629	0.0840	***
Detached house	−0.3139	0.0724	***	0.1869	0.0823	**

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.106883.

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