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Energy poverty in Europe: A multidimensional approach

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The aim of this paper is to develop a synthetic indicator of energy poverty for the purpose of assessing households' well-being across different domains of inequality in access to energy services and to a healthy domestic environment. These dimensions are broadly defined in terms of energy affordability and thermal efficiency, two of the main manifestations of energy poverty highlighted in extant literature (Pye and Dobbins, 2015). Our analysis focuses on Europe because there have been legislation efforts to explicitly recognize the issue and provide a common framework for the protection of vulnerable consumers within the European Union (EU); however, these efforts have not yet been translated into an agreed measure and detailed EU-wide understanding of energy poverty.

Empirical analysis of Europe is facilitated by the availability within Eurostat's "Statistics on Income and Living Conditions" (henceforth EU-SILC) of a set of proxy indicators that may be used to compare energy poverty levels across the EU (Thomson and Snell, 2013; Bouzarovski, 2011; BPIE, 2014).

The paper expands on existing economic literature in employing a fuzzy analysis for the definition of a multidimensional energy poverty index, which is then used to investigate the role of individual and household characteristics in shaping energy poverty. In this way, we are able to capture the interplay of complementary factors affecting energy use (Bouzarovski and Petrova, 2015). Data on socio-demographic characteristics (income poverty, migrant status, age, health conditions), dwelling type and tenure, and the degree of urbanization are considered in order to capture the complexity of the

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key causes of energy poverty. Trends in the energy poverty index are explored at country level between 2012 (year in which a special module within the survey allows us to consider a wider range of variable) and 2014 (the last year for which data are available for all countries) in order to explore the effects of the recent European economic crisis, and to promote more inclusive mechanisms of decision making at both the individual member state and the EU levels.

1. Policy relevance in the EU

The challenges posed by energy poverty have been recently acknowledged by European legislation. The European Commission's "Third Energy Package"[1] urges member states to define the concept and protect "vulnerable customers" (final customers, be they individuals or companies, that have a contract with a supplier of electricity and/or gas). It explicitly refers to "energy poverty" despite the lack of an EU-wide definition of the concept.

Unlike the increasing commitment to alleviate energy vulnerability at the European level, only scattered literature has investigated the actual efficiency and impact of energy-related policy measures at the national level so far. Available evidence reviewed in the present paragraph documents the limited effects of policy intervention on the wellbeing of beneficiaries. The combination of inadequate coverage of the policy interventions, on the one hand, and

[11] The third legislative package for an internal EU gas and electricity market, known as the "Third energy package", consists of two Directives (one concerning common rules for the internal market in gas – 2009/73/EC, one concerning common rules for the internal market in electricity – 2009/72/EC) and three Regulations (one on conditions for access to the natural gas transmission networks – (EC) no. 715/2009, one on conditions for access to the network for cross-border exchange of electricity – (EC) no. 714/2009, and one on the establishment of the Agency for the Cooperation of Energy Regulators ACER – (EC) No 713/2009) adopted in July 2009: https://ec.europa.eu/energy/en/topics/markets-and-consumers/market-legislation.

inadequate targeting processes, on the other hand, seems to translate into a negligible impact on energy poverty.

Member states have promoted a range of policy measures to address all forms of vulnerability of energy consumers. Two categories of such interventions involve the most relevant instruments and practices assessed in the literature: *i*) household energy efficiency schemes, including measures to improve the housing stock, heating systems and household appliances, e.g. through subsidies or grants for energy efficiency improvements and equipment, tax reductions for investments in energy saving, and financing mechanisms involving energy suppliers and distribution system operators (DSO); *ii*) financial support and social tariffs, targeted to vulnerable consumers groups, such as low income, single parents, or over-consumers households, large families, the unemployed, or the retired.[2]

Financial support usually falls within the existing broader social policy, thus benefiting from cost savings in the targeting process. Such typically short-term support is deemed to have a less distortive effect on competition compared to regulated prices. Nevertheless, it heavily relies on public expenditure and thereby is exposed to the on-going fiscal consolidation processes implemented by most EU countries in response to the current economic crisis.

Energy efficiency measures are long-term sector-specific interventions. They are more focused on several root causes of energy vulnerability and may potentially affect other policy areas such as the health costs of treating diseases caused by living in cold homes, efforts to reduce CO_2 emissions, and other macroeconomic benefits (Vulnerable Consumer Working Group, 2013).

The efficient targeting of different schemes has been explored by Sefton (2002) for the UK Home Energy Efficiency Scheme (HEES), and by Faiella and Lavecchia (2015) and Miniaci *et al*. (2014) for the Italian

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[2] The Vulnerable Consumers Working Group (2013) identifies five other categories of member states instruments and practices: consumer protection measures; information and engagement to vulnerable consumers; Transparency and information sharing between stakeholders; and physical measures for industry.

electricity and gas-related benefits (*bonus elettricità* and *bonus gas*) with remarkably comparable results. The UK HEES provided grants to low-income households and disabled people for a package of energy efficiency measures (up to £1.000) and to low-income elderly people households (up to £2.000, HEES plus) for the installation of new central heating systems. According to Sefton's (2002) simulation model, 78% of eligible households live in energy efficient homes and/or earn relatively high incomes, while 82% of the fuel-poor do not qualify for HEES. On the whole, the programme failed to disburse grants to the least efficient homes, jeopardizing its cost-efficiency.

The electricity and gas bonuses in Italy are means-tested [3] discounts on energy bills disbursed to households for their primary residence, independently of their actual consumption. Using EU-SILC data, Miniaci *et al*. (2014) show that more than 70% of households with arrears in paying bills are not eligible for the benefit, as well as 40% of those with electricity (or gas) bill amounts exceeding 5% of their income (10% for gas bills). Faiella and Lavecchia (2015) assess the effectiveness of the same benefits eligibility criteria through a simulation exercise combining data from the Bank of Italy's "Survey on Household Income and Wealth" (SHIW) and the national statistics office's (ISTAT) "Household Budget Survey". They find that 83% of actual recipients are not energy poor according to a "low income, high cost" indicator, adjusted for the inclusion of households with equivalent expenses equal to zero.

Limited coverage caused by ill-suited eligibility criteria contribute to limited effects of the policy interventions on various poverty indicators (Faiella and Lavecchia, 2015; Miniaci *et al*., 2014). Irrespective of targeting inefficiencies, Sefton (2002) more generally reveals the inadequacy of energy efficiency improvements alone to eliminate energy poverty. In the context of the failure of recent UK programmes to lessen the increases in the number of fuel poor households, and of public expenditure withdrawal from previous

[3] Eligible households have a yearly equivalent income indicator (the "Equivalent economic condition indicator", ISEE) below €7.500, or €20.000 for households with more than three dependent people.

energy efficiency schemes (the *Warm Front*), Guertler (2012) provides an assessment of the potential effects of a market-driven financing mechanisms (the so-called *Green Deal Finance*, GDF) on fuel poverty. GDF supports the installation of packages of energy efficiency measures at no upfront cost for the recipient households and with a repayment through a service charge on their energy bill.[4] In this framework, a proposed intervention option (*Assisted Green Deal*) targeted exclusively at fuel poor households would allow them to contribute to the repayments only if the package reduces the combination of energy bills and repayment charge to below the energy poverty threshold. Such a potential mechanism improves on alternative policies to combine with the GDF in terms of both the percentage of households lifted from fuel poverty (75%) and the annual burden cost (£1.05 million, almost equally shared between government and households' contributions).

2. In search of a common definition of energy poverty

Energy poverty research is still at a preliminary stage of understanding across most of the EU member states, and various definitions of energy poverty are adopted both in the literature and across member states.[5] The International Energy Agency (IEA) defines energy poverty as "a lack of access to modern energy services [...] defined as household access to electricity and clean cooking facilities (e.g. fuels and stoves that do not cause air pollution in houses)".[6]

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[4] If the energy bill does not exceed the fuel bill savings (this is the "Golden rule").

[5] See Trinomics (2016) and Pye and Dobbins (2015) for an overview. An official definition of "fuel poverty" is available only in the UK and Ireland, where a range of assistance schemes have been developed in the past decades and national housing condition surveys enable to compare fuel costs required to maintain adequate thermal comfort with household incomes (Bouzarovski *et al.*, 2012; Moore, 2012; Bouzarovski, 2014).

[6] See http://www.iea.org/topics/energypoverty/.

In 2014, an estimated 1.06 billion people in the world had no access to electricity, while 3.04 million relied exclusively on biomasses for cooking and heating (IBRD/The World Bank and IEA, 2017). Energy poverty is emerging as a key policy issue in Europe as well, where 50 to 125 million people are estimated to be "fuel poor" and the number of "vulnerable" households is expected to increase due to rising energy prices (European Fuel Poverty and Energy Efficiency Project, 2009, p. 4).[7]

Energy poverty causes negative consequences in terms of human health, according to available research showing the role of inadequately heated living environments on winter deaths (Marmot Review Team, 2011; Healy, 2003; Fowler *et al*., 2014) and other health problems (i.e. physical health of infants and mental health of adults, according to Liddell and Morris, 2010).

The European Fuel Poverty and Energy Efficiency (EPEE) project laid the ground for an EU-wide common definition by proposing to link it to "household's difficulty, sometimes even inability, to adequately heat its dwelling at a fair, income indexed price" (EPEE, 2009, p 11.). Successively, the European Commission has defined "energy poor households" as those with an actual share of energy products expenditure above a predefined threshold, set at "double the national average ratio number" (European Commission, 2010, p. 16).

2.1. Metrics

The bulk of the literature on energy poverty and affordability has focused on their conceptual identification, especially on the identification of appropriate statistical measures (Hills, 2012). Two main approaches to define energy poverty metrics are adopted in the literature: the *expenditure-based* and the *consensual-based*.

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[7] The terms "energy poverty" and "fuel poverty" (amongst others, e.g. "energy deprivation" or "energy precariousness") are used interchangeably in the literature and by the EU institutions. In both cases, they refer to the "inability of a household to access socially and materially necessitated levels of energy services in the home" (Bouzarovski, 2014).

Expenditure-based indicators are built on the concept of affordable energy consumption. They usually compare a reference expenditure indicator, such as households' expenditure on energy or its share on income, to a certain critical threshold. The most commonly adopted measure of fuel poverty was developed by Boardman (1991) and defines as fuel poor a household whose fuel expenditure on energy services exceeds 10% of its income. In general, budget share indices can be based on a level of energy consumption needed to live in an adequately heated dwelling, or on actual levels of energy consumption. The former approach requires the availability of detailed data on housing conditions, and is thus able to capture energy expenditures deviations from the estimated household energy needs. However, information on the needed amount of consumption (or its cost) is not easily applicable for cross-country comparisons, e.g. at the EU scale, because of the lack of standardized data (with the exception of the "Housing Survey" in the UK). Alternatively, approaches based on the incidence of energy spending on a predefined fraction of households' total consumption or income fail to consider the role of preferences and needs (Miniaci *et al.*, 2014; Moore, 2012; Liddell *et al.*, 2011). Although more easily available and comparable across countries, they ignore vulnerable consumers with no access to energy services due to high costs or limited supply, and they are exposed to the risk of including some relatively wealthy households among those with high energy consumption.

Energy poverty has also been measured according to the consensual approach based on households' subjective assessments of energy affordability, perceived thermal comfort, and dwelling efficiency. Several studies attempted to develop composite indicators for comparison of energy poverty across the EU by using a set of EU-SILC proxy variables (Whyley and Callender, 1997; Healy and Clinch, 2004; Bouzarovski, 2011; Thomson and Snell, 2013). Whyley and Callender (1997) and Healy and Clinch (2004) carry out cross-national comparisons based on data from the "European Community Household Panel" (ECHP) on a subset of EU member states (the former study considers Germany, Ireland, the Netherlands, and the UK, while the latter involves 14 European countries). Both studies report a higher extent of energy poverty in Southern European countries, in particular in Portugal, Greece, Spain, and Italy.

More recently, Thomson and Snell (2013) conducted a cross-comparative analysis of fuel poverty in the EU27 based on EU-SILC cross-sectional household data from year 2007. They measure fuel poverty using proxy indicators that only partially correspond to those selected in our study (ability to keep home adequately warm; arrears on utility bills; leaking roof, damp walls/floors/foundation, or rot in window frames or floor) and aggregate these variables in a single composite indicator by taking their weighted average. Thomson and Snell run separated logistic regression models for each dimension of energy poverty with respect to selected explanatory variables. They show interactions between the three selected indicators of energy poverty, as the inability to heat the home adequately, arrears on utility bills and housing faults (dwelling with leaks, damp or rot) have an impact on each other in their proposed model of consensual measures of fuel poverty. The policy implications of their analysis highlight the role of efficiency improvements.

3. Data and methodology

In our analysis we use data from the EU-SILC database, which covers all persons aged 16 and over residing at the time of data collection in a member state of the EU27 or in Iceland, Norway, Switzerland or Turkey (for more information see Atkinson and Marlier, 2010). The information provided at the household level concerns income, social exclusion and housing conditions data, while topics covered at the individual level concern demographics, education, labour, health and income. Sample selection is based on a nationally representative probability sample of the population residing in private households within the country. Minimum effective sample size is predefined on the basis of statistical and practical considerations (135,000 households as a whole, including Iceland and Norway).

EU-SILC provides a set of proxy indicators that could be regarded as the only available ones for the aim of comparison of energy poverty across the EU. Our analysis focuses on two yearly waves of the EU-SILC cross-sectional database, referring to households' conditions in 2012 and 2014. The 2012 dataset allows us to complement the variables permanently collected in EU-SILC with specific supplementary variables included in an ad hoc module on "Housing conditions". Specifically, these are the *warm* and *cool* variables, which measure the efficiency of heating and cooling systems in the main place of residence respectively. The 2014 dataset is the most recent wave for which we have relevant information on all countries.

We consider two main dimensions of energy poverty: energy affordability and thermal efficiency. Within these dimensions, the selection of variables has been determined by the availability of comparable data at the European level. As shown in table 1, energy affordability is captured respectively by housing and material deprivation indicators: these are the households' answers to questions on the "Ability to keep home adequately warm" and on "Arrears on utility bills". Poor thermal efficiency of buildings is proxied by an objective measure of the condition of the dwelling, indicating whether the dwelling has a problem with a leaking roof and/or damp ceilings, dampness in the walls, floors or foundation and/or rot in window frames and door. Additional key variables provided by the EU-SILC in the 2012 ad hoc module allow to control for other critical housing characteristics. For example, the availability of data on the efficiency of the cooling system during summer time is particularly relevant when computing the well-being of vulnerable households living in thermally poor dwellings in European Southern areas. For this reason, as discussed in the conclusions, it seems crucial to promote the regular collection of such supplementary variables by Eurostat.

Table 1 – *EU-SILC variables concerning energy poverty, by dimension of poverty*

Variable	Question in the survey	Source
Energy affordability		
Thermal comfort	Can your household afford to keep its home adequately warm? (sufficient financial resources)	EU-SILC cross-section survey
Arrears	In the last twelve months, has the household been in arrears, i.e. has it been unable to pay on time due to financial difficulties for utility bills (heating, electricity, gas, water, etc.) for the main dwelling?	EU-SILC cross-section survey
Thermal efficiency		
Dwelling	Do you have any of the following problems with your dwelling/accommodation? A leaking roof; damp walls/floors/foundation; rot in window frames or floor	EU-SILC cross-section survey
Warm	Is the heating system efficient enough to keep the dwelling warm? Is the dwelling sufficiently insulated against the cold? (during winter time)	EU-SILC ad hoc module, 2012
Cool	Is the cooling system efficient enough to keep the dwelling cool? Is the dwelling sufficiently insulated against the warm? (during summer time)	EU-SILC ad hoc module, 2012

As shown in table 2, observed indicators of energy poverty across dimensions have remained relatively stable between 2012 and 2014, with the capacity to maintain the home adequately warm (*thermal comfort*) and the variable on dwelling problems (*dwelling*) showing modest improvements. On the whole, a larger share of European households seems to suffer from efficiency-related issues, while arrears on utility bills and inadequate financial resources affect a smaller proportion of the sample.

When classifying households on the basis of the sex of the household head (the person earning the highest income), it emerges that both problems, energy affordability and energy efficiency, affect women more than men. This is especially true for the ability to keep the home adequately warm, even though women do not seem to exhibit arrears on utility bills more often than men. This evidence calls for a more in-depth analysis of the often-neglected gender perspective in the distributional impact of energy vulnerability in Europe.

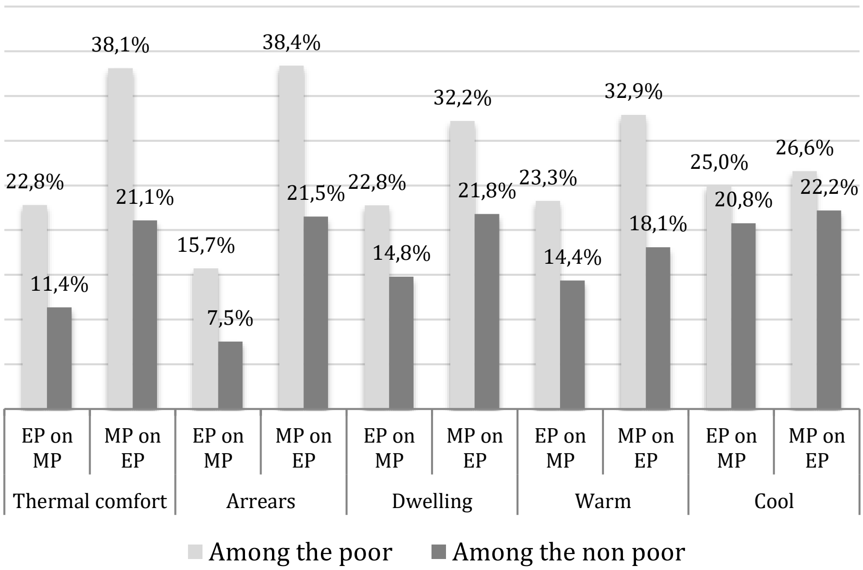
An important issue in defining energy poverty refers to the definition of the target population. According to a dominant perspective among policy-makers, energy poverty would be a symptom of a broader problem of poverty tout-court affecting low-income households. Such an approach translated in official definitions adopted in several European countries (Austria, Belgium, England, and France). However, scholars (e.g. Hills, 2012) consider energy poverty as a useful targeting tool for non-poor households suffering from financial pressure due to energy bills. In the EU-SILC sample, energy poverty appears to be correlated with monetary poverty, as shown in figure 1. However, the overlap in the two populations, of energy poor and of income poor, is far from perfect. All the partial indexes of energy poverty considered here are significantly higher among the households at risk of monetary poverty, pointing to the existence of potential interdependencies between access to energy services and poverty. However, a non-negligible share of European households suffers from affordability and especially energy efficiency problems (dwelling issues, and inefficiency of the heating and cooling systems) even if they are not income poor according to Eurostat's at-risk-of-poverty rate. The policy and academic efforts to define the energy poverty phenomenon may thus contribute to the targeting of states of vulnerability not captured by the most common poverty and material deprivation indicators.

Table 2 – *Share of Europeans reporting energy poverty issues (%; 2012, 2014)*

	2012		2014	
	Total	**Gender gap**	**Total**	**Gender gap**
Energy affordability				
Thermal comfort	14.79%	+3.97% $\chi^2(1)$=184.6854**	14.06% $\chi^2(1)$=10.1498**	+3.20% $\chi^2(1)$= 128.5563**
Arrears	9.18%	-0.14% $\chi^2(1)$=0.1858	9.43% $\chi^2(1)$=16.6919**	-0.28% $\chi^2(1)$= 1.3964
Thermal efficiency				
Dwelling	16.75%	+1.44% $\chi^2(1)$=24.5821**	16.68% $\chi^2(1)$=1.2820	+1.45% $\chi^2(1)$= 23.1009**
Warm	16.43%	+2.92% $\chi^2(1)$= 92.2321**		
Cool	21.76%	+0.95% $\chi^2(1)$=7.9161**		

+ Significant at 10%. * Significant at 5%. ** Significant at 1%.
Notes: the gender gap is computed as the difference between women's and men's shares.
Source: Eurostat, *EU-SILC Cross-Section Database*, 2012 and 2014 waves.

Figure 1 – *Percentage of energy poor among the monetary poor and the non-monetary poor (EP on MP), and percentage of monetary poor among the energy poor and non-energy poor (MP on EP)*



Notes: the at-risk-of-poverty rate is the share of people with equivalised disposable income after social transfer below the at-risk-of-poverty threshold, which is set at 60% of the national median equivalised disposable income after social transfers. Thermal comfort, arrears, and dwelling are considered in 2014, while cool and warm refer to 2012 due to data limitations.
Source: Eurostat, *EU-SILC Cross-Section Database*, 2012 and 2014.

3.2. The fuzzy set approach

In analogy with Botti and D'Ippoliti (2014), we deal with the limitations of existing poverty indicators (as those specifically described above for the case of energy poverty) by employing a fuzzy set approach to the definition and measurement of poverty. In this approach, we assume it is possible to summarize the relevant dimensions of energy poverty in a single measure conceptualised as a continuous variable, normalised to take on values between 1 (indicating full energy poverty) and 0 (indicating total lack of energy poverty).

Energy poverty is a complex phenomenon, manifested in the various symptoms and characteristics experienced by the affected households and individuals. The fuzzy set approach allows us to provide a synthetic measure of a multidimensional phenomenon through a process of identification and measurement of the available proxy indicators, which is less arbitrary compared to previously developed energy poverty indices (Healy and Clinch, 2004; Thomson and Snell, 2013). At the same time, such an approach overcomes some of the weaknesses of the expenditure-based metrics, and has the further advantage of providing a measure of energy poverty by means of a continuous variable. This is relevant in so far as poverty should not be thought of in black and white, but rather in a continuum of disparate intermediate positions may exist.

In the previous paragraph, we identified two relevant dimensions of energy poverty: affordability and efficiency. Both aspects are deemed to represent crucial drivers of energy poverty. As mentioned, the selection of five corresponding variables is affected by the availability of data in the EU-SILC database and improves with respect to previous research in the field (e.g. Healy and Clinch, 2004, and Thomson and Snell, 2013, use only three EU-SILC variables). The operationalization of the fuzzy set approach requires two further steps: the definition of a functional form for the "membership function" and the choice of a method of aggregation and weighting of the dimensions selected.

The definition of a membership function (μA) allows us to assign values between 0 and 1 to each variable of interest (A) in a dimension (x) considered:

$$\mu A(x): X \rightarrow [0,1]$$

where X is the set of the x dimensions.

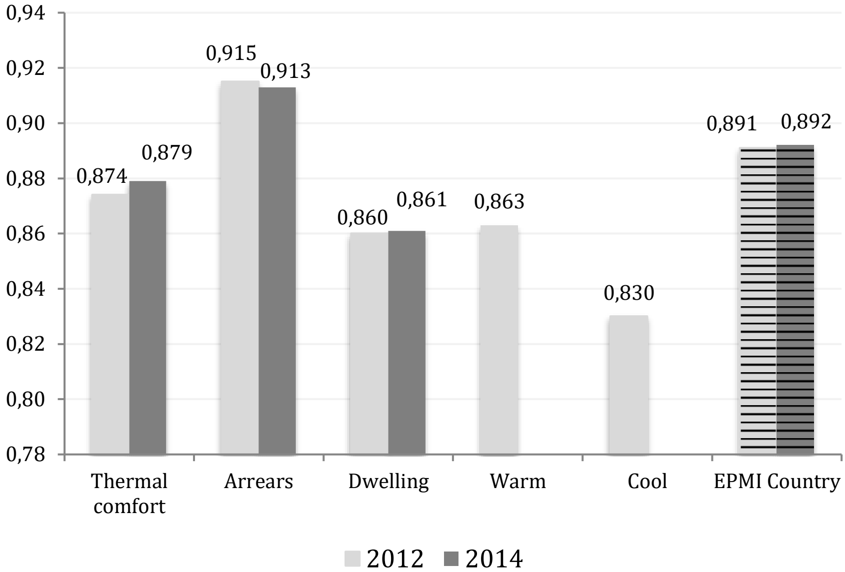
We choose a data-driven method for the definition of the membership function for each variable, whereby μA is equal to the empirical distribution function of each variable x (arranged in increasing order, by *k*). Such an approach allows us to obtain a person's degree of energy poverty that is a function of his/her position in society for each variable, rather than a standard dichotomous approach to poverty measurement based on a certain population characteristic (such as the poverty line). By definition, the application of the membership function to each variable of interest produces a number of standardised variables that necessarily range between 0 and 1, with a variance that is function of the sample distribution of each variable.

For each dimension, the fuzzy indicator is then weighted by the percentage of the reference population without energy poverty problems (the variables are expressed in a same unit of measurement and can be aggregated). This choice reflects the consensual approach to the measurement of energy poverty. According to Gordon *et al.* (2000), the consensual poverty approach is based on the concept of inability to afford items that are considered "basic necessities of life" by most of the general public. The intuition behind the chosen weighting approach lies in the aim to assign a higher weight to the variables in which more people report a lower degree of energy poverty.

Such weighted 'fuzzyfied' variables are then aggregated by averaging. This has been done both separately for each dimension of energy poverty, and jointly to develop a single composite index, the *Energy Poverty Multidimensional Index* (EPMI). Figure 2 reports the results of such a process of 'fuzzyfication' of the variables, which are evidently specular to the evidence reported in table 2. As shown in the figure, the partial fuzzy indicators in the efficiency dimension drag down the composite fuzzy EPMI by exhibiting lower values compared to those in the affordability domain.

We use two different sets of weights in order to capture the role of different possible reference populations. All resident households in the same country are used for the *EPMI Country*, and the overall European population for the *EPMI EU*. As shown in figure 3, on average higher degrees of energy poverty are documented for the indicators obtained taking as weights the percentage of non-poor

Figure 2 – *Partial fuzzy indexes of energy poverty, and the EPMI Country*



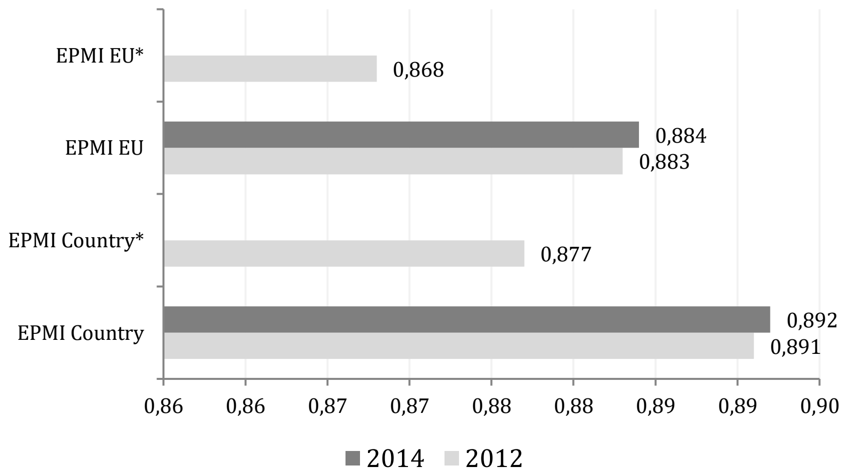
Source: Eurostat, *EU-SILC*, 2012, 2014.

European households than the percentage of fellow countrymen.

For every specification of the EPMI, energy poverty levels remained approximately stable between 2012 and 2014. If compared to an increasing share of monetary deprived households – the ARPR increased by 1.1% in the same time interval – such invariance in the years following the European crisis may suggest different possible interpretations. On the one hand, both energy affordability and housing efficiency may depend more on structural dynamics compared to monetary poverty, and are therefore less likely to move in the short term. On the other hand, this finding could confirm the low income elasticity of energy demand.

Both indicators have also been computed including the additional indicators on the efficiency of the dwelling (*warm* and *cool*) available from the 2012 EU-SILC ad hoc module on "Housing condition". The synthetic indicators of energy poverty reported in figure 3 highlight the risk of underestimating energy vulnerability when relevant information on the efficiency of the heating and cooling systems (provided only in the 2012 ad hoc module) is not included in the analysis. The EPMI computed on the extended set of efficiency indicators consistently exhibits higher energy poverty than the EPMI on the smaller set.

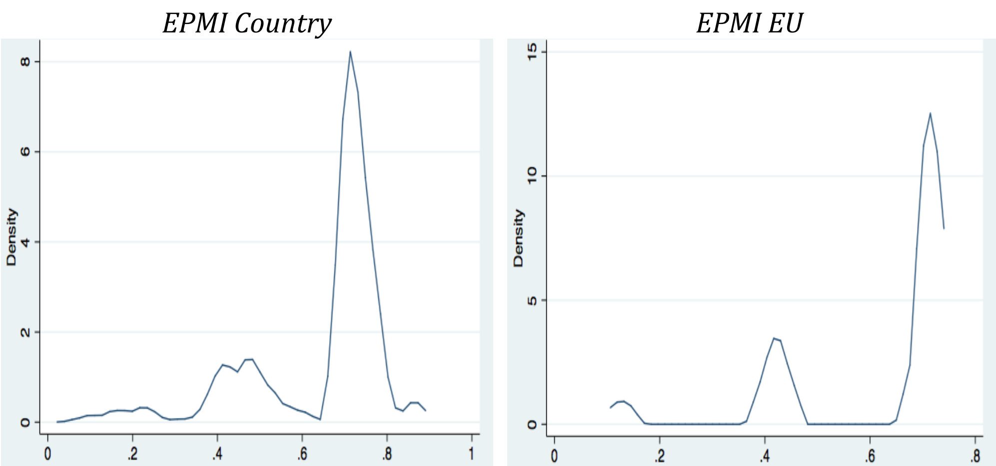
Figure 3 – *Average EPMI, different specifications*



Notes: the EPMI Country* and EPMI EU* indexes include the two variables only available in the 2012 ad hoc module on "Housing conditions": "Dwelling comfortably warm during winter time" (question HC060 in the EU-SILC survey); and "Dwelling comfortably cool during summer time" (question HC070).
Source: Eurostat, *EU-SILC Cross-Section Database*, 2012 and 2014 waves.

Indicators derived with the described fuzzy set approach may be considered as measures of the degree of energy poverty relative to the rest of the reference population. By construction, they necessarily range between zero and one, and all households in the sample lie somewhere between the two poles. Figure 4 shows the distribution of the EPMI in the population, obtained through Kernel density estimation. The indexes do not appear to be smooth, because the variables composing them are categorical and not continuous, but they allow us to overcome the limits of the dichotomous approach to poverty. Specifically, they show various groups of the population clustering at different degrees of energy poverty. The indicator based on each country's reference population is evidently more stretched compared to that estimated on the basis of the EU distribution as benchmark.

Figure 4 – *Distribution of the Energy Poverty Multidimensional Index (EPMI)*



Notes: the distributions are estimated through kernel density estimation, Epanechnikov method.
Source: Eurostat, EU-SILC *Cross-Section Database*, 2012 and 2014.

Previous analyses based on subjective measures of energy poverty within EU-SILC document a pronounced geographical variability of energy vulnerability across Europe (Buzar, 2007; Healy and Clinch, 2004; Thomson and Snell, 2013; Bouzarovski, 2014; Bouzarovski and Tirado Herrero, 2017). Former socialist states in Central and Eastern Europe (CEE), as well as Mediterranean EU member states, exhibit the highest prevalence of energy poverty according to subjective indicators, though with distinctly different determinants. Significant shares of the population in CEE countries is energy poor due to a combination of socio-economic and climate factors: since the post-socialist transition, dramatic price increases and a lack of adequate social assistance and investment in energy efficiency hit populations that often live in inhospitable climates. In contrast, the notable prevalence of energy poverty in the Mediterranean countries has been associated to inadequate heating systems and overall poor quality of residential dwellings.

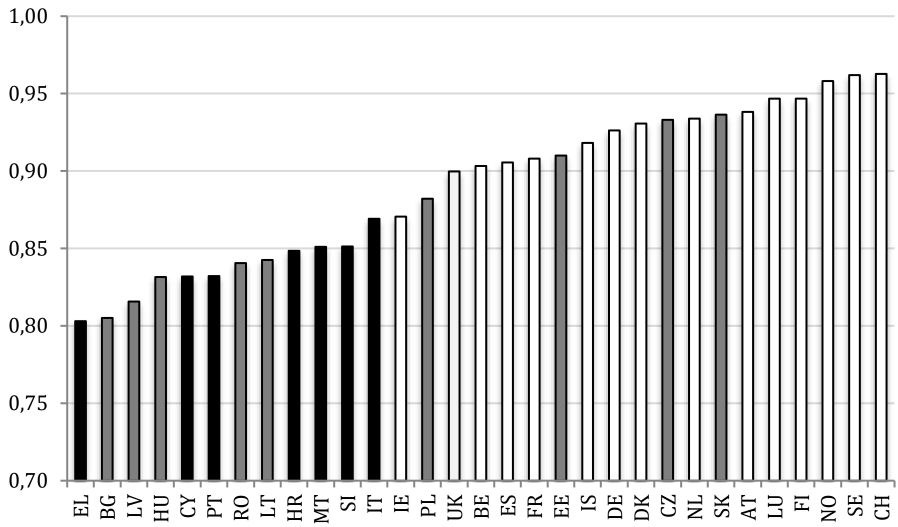
The landscape of energy poverty in the EU according to our synthetic indicator, depicted in figure 5, is relatively consistent with the above-described evidence from previous studies. The countries most affected by high degrees of energy poverty are in the macro regions of CEE and Southern Europe.

4. Micro and macro drivers of energy poverty

Despite the lack of a common European definition, several studies have attempted to estimate the main factors contributing to energy poverty in Europe. The combination of three main drivers of energy poverty has been discussed in the literature: low income levels, high energy prices, and poor housing energy efficiency (for an overview, see Pye and Dobbins, 2015).

In order to measure the role of different drivers of energy poverty in Europe operating at the household and contextual levels, we run OLS regressions of the *EPMI Country* on both sorts of factors. Household-level explanatory variables allow to control for demographic factors such as gender, age, and nationality of the head of the household. Furthermore, we consider a range of factors spanning from the households' disposable income to various measures of housing

Figure 5 – *EPMI by country (averages, 2014)*



Notes: Southern European countries in black histograms; Eastern European countries in grey histograms; rest of Europe in white histograms.
Source: Eurostat, *EU-SILC Cross-Section Database*, 2014.

conditions: tenure status, dwelling type, and the degree of urbanization of the location where the household lives. Concerning the macro regressors, we consider fixed effects for the country of residence, and three widely diffused sets of variables measuring energy prices (indexes of electricity and natural gas prices for a medium sized household), efficiency (energy intensity), and the energy requirements of buildings induced by the severity of local weather conditions (heating degree days).

The main results are reported in table 3. Across the different estimations, household income is always negatively correlated with energy poverty. Consistently with the descriptive statistics, women suffer from higher degrees of energy vulnerability. More remarkably, and in contrast to consolidated evidence, older people appear to experience lower degrees of energy poverty (compare e.g. Wright, 2004).

Previous works on energy poverty has so far tended to focus on traditionally visible groups, such as the elderly and rural populations (Bouzarovski, 2014). In our empirical investigation, we also explored the condition of energy deprivation of other marginal social groups, such as migrants and private renters. This way, we aim to contribute to the recognition of misrepresented groups of energy poor and their specific needs, thus promoting more inclusive mechanisms of decision making at both the member states and the EU levels. Following the energy justice conceptual framework (Jenkins *et al*., 2016; Walker and Day, 2012), the identification of specific marginalized groups actually affected by energy poverty may heavily contribute to recognition-based justice and more inclusive representation mechanisms in remediation strategies (procedural justice).

Indeed, from our estimates it emerges that non-EU citizens experience systematically higher levels of energy poverty compared to Europeans, both those residing in their home state and intra-EU migrants.[8] The dwelling type also affects energy poverty: households living in detached housing, as well as those living in thinly-populated areas, fare worse than those in any other dwelling type, possibly because of their greater energy demand. Tenure status too is expected to have an impact on energy poverty. All types of private renters suffer from greater energy poverty compared to owners: this could be due to their restricted opportunity to profit from and invest in efficiency-improving measures.

[8] Citizenship is defined by Eurostat as the particular legal bond between the individual and his/her State acquired by birth or naturalisation, whether by declaration, option, marriage or other means according to the national legislation. It corresponds to the country of which the passport is used (http://ec.europa.eu/eurostat/web/income-and-living-conditions/methodology/list-variables).

Table 3 –*Drivers of energy poverty: regressions on 2012 and 2014 EU-SILC data*

	2012		**2014**		**All observations**	
	(1) only micro explanatory variables	**(2) micro and country explanatory variables**	**(3) only micro explanatory variables**	**(4) micro and country explanatory variables**	**(5) only micro explanatory variables**	**(6) micro and macro explanatory variables**
Total disposable hh income	3.44e-06***	2.30e-06***	3.46e-06***	2.58e-06***	3.47e-06***	2.94e-06***
	(6.45e-08)	(3.95e-07)	(6.46e-08)	(3.86e-07)	(6.10e-08)	(3.62e-07)
Gender: man	0.0113***	0.00979***	0.00925***	0.00869***	0.0103***	0.00885***
	(0.00159)	(0.00184)	(0.00157)	(0.00245)	(0.00112)	(0.00210)
Age	0.000951***	0.000858***	0.000930***	0.000896***	0.000939***	0.000914***
	(4.91e-05)	(0.000220)	(4.90e-05)	(0.000185)	(3.47e-05)	(0.000236)
Citizenship: European Union (except country of residence)						
Country of residence	0.0123**	0.00662	0.0114**	0.00390	0.0119***	0.00750
	(0.00486)	(0.00844)	(0.00500)	(0.00580)	(0.00348)	(0.00718)
Other country	−0.0344***	−0.0270***	−0.0421***	−0.0361***	-0.0383***	−0.0314***
	(0.00677)	(0.00808)	(0.00681)	(0.00788)	(0.00480)	(0.00728)
Dwelling type: detached house						
Semi detached or terraced	0.0167***	0.0119**	0.00368	0.00596	0.0102***	0.00817*
house	(0.00237)	(0.00466)	(0.00237)	(0.00401)	(0.00168)	(0.00442)
Apartment or flat in a building	0.0268***	0.0259***	0.0202***	0.0236***	0.0236***	0.0246***
with < 10 dwellings	(0.00246)	(0.00669)	(0.00242)	(0.00630)	(0.00173)	(0.00735)
Apartment or flat in a building	0.0578***	0.0538***	0.0529***	0.0492***	0.0554***	0.0539***
with 10 or more dwellings	(0.00218)	(0.00666)	(0.00218)	(0.00545)	(0.00154)	(0.00659)

(*continued*)

(*continues*)

	2012		2014		All observations	
	(1) only micro explanatory variables	**(2) micro and country explanatory variables**	**(3) only micro explanatory variables**	**(4) micro and country explanatory variables**	**(5) only micro explanatory variables**	**(6) micro and macro explanatory variables**
Tenure status: outright owner						
Owner paying mortgage	0.00139	-0.0162***	-0.00123	-0.0156***	0.000130	-0.0145***
	(0.00266)	(0.00366)	(0.00265)	(0.00391)	(0.00188)	(0.00369)
Tenant or subtenant paying rent	−0.0131***	−0.0429***	−0.0150***	−0.0413***	−0.0141***	−0.0443***
at prevailing or market rate	(0.00227)	(0.00420)	(0.00221)	(0.00538)	(0.00159)	(0.00497)
Accomodation rented at a	−0.0310***	−0.0600***	−0.0393***	−0.0624***	−0.0349***	−0.0647***
reduced rate	(0.00277)	(0.00739)	(0.00290)	(0.00911)	(0.00200)	(0.00842)
Accomodation provided free	−0.0232***	−0.0221**	−0.0167***	−0.0168**	−.0198***	−0.0195**
	(0.00304)	(0.00854)	(0.00292)	(0.00709)	(0.00211)	(0.00876)
Degree of urbanization: densely populated area						
Intermediate area	0.00666***	0.000350	0.0135***	0.00543*	0.0102***	0.00383
	(0.00191)	(0.00420)	(0.00186)	(0.00284)	(0.00133)	(0.00345)
Thinly populated area	0.00416**	−0.00447	0.00121	−0.00325	0.00280**	−0.00300
	(0.00196)	(0.00482)	(0.00199)	(0.00412)	(0.00140)	(0.00502)

(*continued*)

(*continues*)

	2012		2014		All observations	
	(1) only micro explanatory variables	**(2) micro and country explanatory variables**	**(3) only micro explanatory variables**	**(4) micro and country explanatory variables**	**(5) only micro explanatory variables**	**(6) micro and macro explanatory variables**
Macro variables:						
HDD						−0.0437**
						(0.0170)
Energy intensity						−0.000474**
						(0.000220)
Natural gas price						−0.00225*
						(0.00113)
Electricity price						0.129
						(0.0759)
Constant	0.741***	0.835***	0.747***	0.826***	0.744***	1.045***
	(0.00632)	(0.0143)	(0.00640)	(0.0140)	(0.00456)	(0.0629)
Observations	*59,523*	*59,523*	*59,929*	*59,929*	*119,452*	*100,634*
R-squared	*0.071*	*0.105*	*0.072*	*0.105*	*0.071*	*0.100*

*** p<0.01, ** p<0.05, * p<0.1.

Notes: Standard errors in parentheses. Country fixed effects are not shown in the table, those from equation (4) are shown in figure 3. See Annex 1 for OLS regressions including all macro variables for separated regressions for years 2012 and 2014.
Source: Eurostat, *EU-SILC Cross-Section Database*, 2012 and 2014 waves.

The role of macro variables has been investigated in order to control for different factors systematically affecting energy efficiency and affordability at the country level.[9] The energy intensity indicator measures the energy consumption of a country as a share of its GDP, and it is a proxy of its overall energy efficiency.[10] As shown in table 3, less efficient countries tend to report greater degrees of energy poverty. The Heating degree days (*HDD*) indicator measures the severity of cold in a specific time period, and it is an indirect indicator of the level of energy consumption needed at the country level to keep the home adequately warm.[11] As was expected, energy poverty is more severe in countries with high-energy needs. Electricity and natural gas prices for a medium sized household capture the potential role of households' high-energy bill on energy vulnerability.[12] In this case, results are less clear-cut. While gas prices negatively impact energy poverty, as expected, electricity prices are positively

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[9] In regressions 2 and 4, the macro variables HDD, denoting energy intensity, as well as electricity and natural gas prices are not included because of collinearity with the country dummy variables. The results concerning all other variables are in any case broadly in line with the 2012 and 2014 regressions of the EPMI, reported in Annex 1.

[10] The energy intensity indicator is the ratio between the Gross Inland Consumption of Energy and the Gross Domestic Product calculated for a calendar year. The Gross Inland Consumption of Energy is calculated as the sum of the Gross Inland Consumption of the five types of energy: coal, electricity, oil, natural gas and renewable energy sources. Each of these figures is calculated as an aggregation of different data on production, storage, trade (imports/exports) and consumption/use of energy (http://ec.europa.eu/eurostat/en/web/products-datasets/-/TSDEC360).

[11] Eurostat's method for the calculation is the following: (18° C – *Tm*) per day if *Tm* is lower than or equal to the defined heating threshold of 15° C, and nil if *Tm* is greater than 15° C, where *Tm* is the mean outdoor temperature [(*Tmin* + *Tmax*)/2] over a period of *d* days. Calculations are executed on a daily basis (*d* = 1), added up to a calendar month – and subsequently to a year – and published for each member state (available at: http://ec.europa.eu/eurostat/web/energy/data).

[12] Electricity prices for household consumers are based on prices for the medium standard household consumption band, namely one with annual electricity consumption between 2,500 and 5,000 kWh. Natural gas prices for households consumers are based on prices for the medium standard household consumption band, with annual natural gas consumption between 20 and 200 GJ, in other words between 5,556 and 55,556 kWh.

correlated to the EPMI, indicating a possible incentive effect to promote efficiency improving measures in countries where electricity is more expensive. Anyway, the role of energy affordability in shaping energy poverty requires further research.

Figure 6 – *Energy poverty in Europe: country deviations with respect to Austria, year 2014*

Notes: the map shows the country fixed effects from regression 4 in table 3; all coefficients shown are statistically significant at 0.01 significance level for all country coefficients with the exception of Germany ($p < 0.05$) and Switzerland ($p < 0.1$). The coefficients for the Czech Republic, Estonia and Slovakia are not statistically significant and therefore are not reported in the map.
Source: Eurostat, *EU-SILC Cross-Section Database*, 2012 and 2014 waves.

Finally, in regressions 2, 4, and 6 in table 3 we also control for country fixed effects, finding spatial patterns of energy poverty across the EU that are mostly consistent with the descriptive evidence presented in figure 5. The statistically significant country coefficients are reported in figure 6. Households living in Eastern and Southern European countries are confirmed to be most affected by high degrees of energy poverty. Greece, Bulgaria, Latvia, Cyprus, Lithuania, Hungary and Portugal show the highest negative coefficients. Households in Romania, Italy, Croatia, Malta and Spain also exhibited significant levels of energy poverty in 2012 and 2014. Ireland, that has recently been included in a third group of countries with above-average energy poverty rates (in addition to CEE and Mediterranean countries; Bouzarovski, 2014), is found to exhibit relatively high-energy poverty. Remarkably, living in various Scandinavian countries (Denmark, Norway and Iceland) is associated with a rather poor performance in terms of energy poverty, comparable to that of countries traditionally exposed to relatively notable shares of energy deprivation, such as France, Belgium, and the UK.

4. Conclusions and policy implications

In recent years, energy poverty, namely the lack of access and/or the inability to afford socially and materially required levels of energy services at home, has attracted growing policy and academic interest in Europe. The European Union recognized such phenomenon in the framework of the "Third Energy Package", while the European Economic and Social Committee (EESC) warned of the implications of the liberalization of energy markets and of the current crisis on energy vulnerability (EESC, 2013). However, in the European Union, there is no common definition of energy poverty and the issue is explicitly recognized in the legislation of very few countries (Cyprus, France, Ireland, Slovakia, and the United Kingdom).

Owing to the multidimensional nature of the issue, a number of energy poverty metrics have been developed according to two main approaches: expenditure-based (built on data on household energy expenses) and consensual-based (referring to perceived energy deprivation). A handful of studies analysed the extent and the determinants of energy poverty across Europe in the spirit of the latter approach, using EU-SILC survey data on subjective vulnerability in the energy domain (Bouzarovski, 2014; Healy and Clinch, 2004; Thomson and Snell, 2013).

This paper proposes a fuzzy set approach to the definition of energy poverty, introducing an innovative multidimensional indicator summarizing two main dimensions of affordability and efficiency in a single continuous indicator of energy poverty. For each dimension considered, we selected corresponding variables available in the EU-SILC database for the years 2012 and 2014.

Our approach allows us to overcome the typical limitations of headcount poverty ratios, based on the definition of a predefined threshold forcing a dichotomous approach to the measurement of poverty. We summarize the relevant dimensions of energy poverty in a single index conceptualised as a continuous variable normalised to take on values between 0 (indicating full energy poverty) and 1 (indicating the total lack of energy poverty). The derived indicator, the Energy Poverty Multidimensional Index (EPMI), captures a household's degree of energy poverty relative to the rest of the population, in which we use a data-driven weighting method assigning a higher weight to the poverty dimensions in which more people show low or no energy poverty.

Different specifications of the EPMI appear to be stable between 2012 and 2014 despite the increasing trend in the at-risk-of-poverty rate (ARPR) during the same period (+1.1%). Possible explanations include the more structural dynamics driving energy poverty adjustments compared to monetary deprivation, and the low-income elasticity of energy expenditure.

Additional efficiency variables have been included in the analysis amongst those provided by the EU-SILC in the 2012 ad hoc module on "Housing conditions", with specific reference to dwellings' heating and cooling systems efficiency. The EPMI obtained including such additional data highlights higher degrees of energy poverty. This finding demonstrates the need to implement a regular collection –

possibly within the same EU-SILC – of supplementary information at the household level in order to attain a more accurate measure of energy vulnerability.

In order to estimate the role of micro and macro drivers of energy poverty, we run OSL regressions on the EPMI. Low income levels, one of the three major driving factors of the inability to access or afford adequate energy services, are confirmed to raise energy poverty. An additional range of factors is also pertinent to the rise of energy poverty: being a woman, a migrant, and a private renter significantly increases the exposure to energy affordability and efficiency issues. Dwelling type and home localization also seem to matter, as well as belonging to a household living in detached housing, and living in thinly-populated areas.

Higher incidence of energy poverty is still concentrated in the Mediterranean and CEE countries in the most recent years following the European crisis. Domestic energy prices impact energy poverty differently. While the gas price negatively affects the probability to experience energy poverty, as expected, the electricity price is positively correlated to the EPMI, possibly acting as an incentive to adopt and promote efficiency improvements.

Descriptive statistics and both the micro and macro factors investigated in our empirical analysis suggest that thermal efficiency plays a crucial role in shaping individual and countries' average degrees of energy poverty.

Therefore, the European evidence suggests a policy intervention based on a greater support offered to households' energy efficiency in order to address the structural nature of energy poverty across Member States. However, as noted in previous literature, inadequate funding and poor targeting processes need to be tackled to support the effectiveness of energy efficiency policy measures. At the member state level, the design of effective targeting measures would benefit from the dissemination of best practices explicitly targeted at the energy poor (e.g. the Scandinavian countries' experience with measures devoted to the social housing stock). At the European Union level, a greater allocation of EU funds to housing renovation and retrofit programmes, especially in CEE and Mediterranean countries, should be encouraged given the limited capacity of household financing and restricted access to private capital markets for low-income and energy vulnerable households.

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Annex

Table A1 – *Drivers of energy poverty: regressions on 2012 and 2014 EU-SILC cross-sectional data*

	2012	**2014**
Total disposable hh income	2.69e-06***	3.10e-06***
	(3.61e-07)	(3.90e-07)
Gender: men	0.00899***	0.00875***
	(0.00191)	(0.00288)
Age	0.000855***	0.000974***
	(0.000267)	(0.000212)
Dwelling type: detached house		
Semi detached or terraced house	0.0111**	0.00507
	(0.00511)	(0.00442)
Apartment or flat in a building with < 10 dwellings	0.0253***	0.0239***
	(0.00817)	(0.00720)
Apartment or flat in a building with 10 or more dwellings	0.0552***	0.0524***
	(0.00783)	(0.00588)
Tenure status: outright owner		
Owner paying mortgage	–0.0155***	–0.0135***
	(0.00346)	(0.00426)
Tenant or subtenant paying rent at prevailing or market rate	–0.0469***	–0.0414***
	(0.00444)	(0.00627)
Accomodation rented at a reduced rate	–0.0637***	–0.0668***
	(0.00786)	(0.00972)
Accomodation provided free	–0.0220**	–0.0174**
	(0.00998)	(0.00795)
Degree of urbanization: densely populated area		
Intermediate area	0.000992	0.00659**
	(0.00474)	(0.00317)
Thinly populated area	–0.00426	–0.00196
	(0.00585)	(0.00477)
Citizenship: European Union (except country of residence)		
Country of residence	0.0124	0.00285
	(0.0115)	(0.00739)
Other country	–0.0232**	–0.0392***
	(0.0105)	(0.00875)

(*continued*)

(*continues*)

	2012	2014
Belgium	−0.0325***	−0.0258***
	(0.00300)	(0.00241)
Bulgaria	−0.110***	−0.101***
	(0.00797)	(0.00904)
Czech Republic	−0.00180	0.0158**
	(0.00548)	(0.00658)
Germany	−0.00841***	−0.00190
	(0.00128)	(0.00176)
Denmark	−0.0138***	−0.0199***
	(0.00197)	(0.00312)
Estonia	−0.0273***	−0.00113
	(0.00570)	(0.00709)
Greece		−0.114***
		(0.00637)
Spain	−0.0302***	−0.0373***
	(0.00321)	(0.00415)
France	−0.0236***	−0.0303***
	(0.00148)	(0.00170)
Croatia		−0.0596***
		(0.00868)
Hungary	−0.102***	−0.0753***
	(0.00647)	(0.00771)
Ireland	−0.0402***	−0.0546***
	(0.00375)	(0.00405)
Italy	−0.0799***	−0.0722***
	(0.00262)	(0.00362)
Lithuania	−0.101***	−0.0774***
	(0.00620)	(0.00790)
Luxemburg	−0.0211***	−0.0329***
	(0.00464)	(0.00580)
Latvia	−0.113***	−0.0940***
	(0.00667)	(0.00769)
Poland	−0.0604***	−0.0352***
	(0.00613)	(0.00755)
Portugal	−0.0696***	−0.0764***
	(0.00603)	(0.00659)
Romania	−0.0975***	−0.0663***
	(0.00793)	(0.00908)

(*continued*)

(*continues*)

	2012	**2014**
Sweden	0.00657***	0.00972***
	(0.00218)	(0.00214)
Slovakia	−0.0136**	0.0146*
	(0.00585)	(0.00708)
United Kingdom	−0.0233***	−0.0201***
	(0.00427)	(0.00416)
Constant	0.823***	0.809***
	(0.0186)	(0.0155)
Observations	*48,809*	*51,825*
R-squared	*0.102*	*0.100*

*** p < 0.01, ** p < 0.05, * p < 0.1.
Notes: standard errors in parentheses.
Source: Eurostat, *EU-SILC Cross-Section Database*, 2012 and 2014 waves.