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Exploring the effect of energy transition on energy poverty in the european union: Empirical evidence

Q1 Giuseppe Scandurra[a], Alfonso Carfora[b], and Antonio Thomas[c]

[a]Department of Management and Quantitative Studies, University of Naples Parthenope, Naples, Italy; [b]Department of Economics and Law, University of Macerata, Macerata, Italy; [c]Department of Business and Economics, University of Naples Parthenope, Naples, Italy

ABSTRACT

During the past few years, the risk of energy poverty has become a reality for an increasing number of households in the European Union and worldwide. Institutions react to this problem basically by introducing new policy measures. However, their efforts collide with two significant issues: (1) the difficulty of objectively measuring energy poverty among countries and (2) the understanding of the cause-effect relationship among policy measures and their impact on energy poverty. In this study, we propose a composite measure of energy poverty alternative to the existing approaches in order to make more effective time comparisons across member states of European Union. Then, we verify whether the investments to support energy transition implemented so far has been able to affect energy poverty among European Union countries. Outcomes reveal that energy transition can be considered a means to alleviate energy poverty, supporting the efforts of policymakers who propose measures toward the energy transition.

KEYWORDS

Affordability; energy poverty; European states; sustainable energy transition

1. Introduction

Since the 1990,' the issue of *energy poverty* (EP) has emerged through the publication of the masterpiece *Fuel Poverty: From Cold Homes to Affordable Warmth* (Boardman 1991), which formalized the previous concept proposed by Isherwood and Hancock (1979). At the European Union (EU) level, the first implications about protecting and supporting energy-poor consumers go back about 20 years. Currently, EP has become central in EU economic policies as many efforts have been made to reduce the population's inequalities.

This interest is intrinsically linked to the concept of *energy transition* (ET), which, as is well known, is not limited to the gradual replacement of fossil fuel – based generation sources with clean energy systems but is a paradigm that affects the entire social and economic system. In doing so, ET should involve the three primary factors whose interaction causes EP – the low income, the high energy price, and the energy-inefficient housing (EU European Union 2022) – widely contributing to achieving Sustainable Development Goal 7.

However, this objective is likely to be hampered by the lack of a shared measure of EP among countries and the absence of an analysis of the effects of ET measures on EP itself. With this in mind, the aim of this study was twofold. First, it proposes a composite measure of EP to make possible comparisons across EU countries. Until now, none of the many proposed indices has been judged

CONTACT Giuseppe Scandurra giuseppe.scandurra@uniparthenope.it Department of Management and Quantitative Studies, University of Naples Parthenope, Via Generale Parisi 13, Naples 80133, Italy

satisfactory. Second, the study assesses whether and in what direction policy measures implemented to promote ET have affected EP among EU member states (EU – MS).[1]

To this purpose, a wide set of variables collected from different Eurostat (2022) databases covering the years 2007–2020 for 26 EU – MS has been applied. To the best of our knowledge, just few studies have investigated the possibility that ET can facilitate a reduction of EP among EU – MS minimizing regional inequalities and supporting a so-called just-transition (e.g., Bartiaux et al. 2019; Bouzarovski and Tirado Herrero 2017; Carfora and Scandurra 2024; Kelly et al. 2020). Hence, this study intends to contribute to the specific literature on this issue, shedding light on a knowledge gap linked to the difficulty of objective comparisons about the level of EP among the EU – MS, and on the consequences related to the implementation of energy policy measures resulting from the objectives of ET.

This paper is organized as follows. After this introduction, section 2 reports the theoretical framework, section 3 points out the indicator proposed to measure EP and discusses the spatial and yearly differences among EU – MS. Section 4 introduces the model and explores the key factors affecting the EP indicator, while section 5 provides an overall discussion. Section 6 includes concluding remarks and policy implications.

2. Theoretical framework

Since the oil crisis of the 1970s, the concept of EP has emerged as a critical element in assessing households' economic and social conditions (Bouzarovski and Petrova 2015; Bouzarovski, Petrova, and Sarlamanov 2012; Castaño-Rosa et al. 2019; Hasanujzaman and Omar 2022; Ramos, Alvargonzález, and Moreno 2022). Li et al. (2014) argued that many scholars use EP interchangeably with fuel poverty. The *Warm Homes and Energy Conservation Act 2000* defined a situation of fuel poverty as involving "a person [who] is a member of a household living on a lower income in a home which cannot be kept warm at reasonable cost." Although the border between the concepts of fuel poverty and EP are often thin (e.g., Li et al., 2010), we can consider EP a broader concept that includes the deprivation of well-being and the inability to satisfy basic needs (EC European Commission 2022). If fuel poverty has a detrimental effect on quality of life, health, and well-being, people living in EP also experience poor hygiene and comfort, including uncomfortable indoor temperatures, poor air quality, and exposure to hazardous substances. These conditions can reduce employee productivity, cause health issues, and even increase the death rate. EP and fuel poverty are then descriptors of household energy consumption problems. According to Eurostat (2023), approximately 69 million people in the EU – 9.3% of the population – were unable to keep home adequately warm, and about 6.4% of the EU population is in arrears with utility bills.

Moreover, Eurostat (2022) indicates that the percentage of the population living in homes with leaks, dampness, or rot is almost 13%. This phenomenon is probably underestimated because of the joint effects of the recent pandemic and the war between Russia and Ukraine, which are causing difficulties in the energy supply chain and affecting the *energy security* of European households. The pandemic has caused many people to lose their jobs or reduce their living standards. At the same time, international tensions have boosted an inflationary effect, estimated at 9% to 11% in the EU in 2022, mainly because of the strong increase in energy commodity prices. That is because the EU generation system is highly dependent on non-EU countries from which EU – MS import a large part of the resources needed to meet the energy demand from productive systems and households (Haas 2019; van Bommel and Höffken 2021).

Due to this emergency, national policymakers and EU institutions agree that it is urgent and necessary to adopt measures to tackle EP for vulnerable consumers. These measures can be quite

[1]Countries included are the following (International Organization for Standardization (ISO) 2 codes are in parentheses): Belgium (BE); Bulgaria (BG); Czechia (CZ); Denmark (DK); Germany (DE); Estonia (EE); Ireland (IE); Greece (EL); Spain (ES); France (FR); Croatia (HR); Italy (IT); Latvia (LV); Lithuania (LT); Luxembourg (LU); Hungary (HU); the Netherlands (NL); Austria (AT); Poland (PL); Portugal (PT); Romania (RO); Slovenia (SI); Slovakia (SK); Finland (FI); Sweden (SE); and the United Kingdom (UK), despite its recent exit from the EU. Because of a lack of a complete time series, Cyprus (CY) and Malta (MT) were excluded.

heterogeneous as, in addition to the already-mentioned low-income, high-energy costs, and inefficient buildings, "a wide range of socioeconomic issues connected with poverty in general and housing tenure concerns" (EC (European Commission), 2020) plays a relevant role on the EP level, as they cause significant physical and psychological stress for families in situations of EP.

To contrast the negative effects of higher energy costs paid by households (and by the productive systems) and reduce the degree of dependence on fossil fuels imported from non-EU countries, the introduction of a price cap for gas was a first attempt to mitigate the price dynamic (EU European Union 2022; Kovacic and Di Felice 2019). The EC has simultaneously accelerated the ET process, asking EU – MS for a joint effort and regulatory simplifications to push toward clean energy and drastically reducing the gas flow from Russia, from which Europe was importing about 40% in 2021 (Flanagan et al. 2022).

To face this framework, researchers from different disciplines have focused the EP diagnosis mainly in three directions: i) the effects of EP; ii) the factors fostering this issue; iii) the measure of EP. These investigations have concerned both the less developed countries, where the problem of EP mainly regards the *availability* and accessibility of resources (Ozughalu and Ogwumike 2019; Qurat-ul-Ann and Mirza; Rosa et al. 2020; Hasanujzaman and Omar 2022), and the more developed ones, where the mainstream concerns the *affordability* of energy sources (Dubois and Meier 2016; Stojilovska, Yoon, and Robert 2021; Wang et al. 2023).

Focusing on the EU – MS, EP has gained considerable attention both in a single nation, such as United Kingdom (Fahmy, Gordon, and Patsios 2011; Rosa et al. 2020), Spain (Alvarez and Tol 2021; Bagnoli and Bertoméu-Sánchez 2022; Barrella et al. 2022), France (Kahouli 2020; Legendre and Ricci 2015), Lithuania and Greece (Spiliotis et al. 2020; Streimikiene et al. 2021), and the Netherlands (Mashhoodi, Stead, and Timmeren 2019), as well as at the whole-EU level (e.g., Thomson and Snell 2013; Llorca, Rodriguez-Alvarez, and Jamasb 2020; van Hove, Dalla Longa, and van der Zwaan 2022; Huang, Ming, and Duan 2022; Ramos et al. 2022).

Regarding the entire EU, a significant paper by Thomson and Snell (2013) examined the explanatory determinants of EP at the home level using cross-sectional data from European Union Statistics on Income and Living Conditions (EU – SILC) for 2007. Their outcomes indicated that EP is particularly severe in rural areas and southern and eastern European countries. Applying a descriptive analysis, Bouzarovski and Tirado Herrero (2017) also found spatial disparities. They concluded that EP is more widespread in the peripheral nations of the EU than in those central regions and made a distinction among three groups of European countries: (1) North and West, (2) East, and (3) South.

Focusing on a sample of 28 EU countries from 2007 to 2014, Dubois and Meier (2016) investigated an analytical framework of EP and demonstrated how it differs dramatically among nations. A heterogeneous pattern emerges, in which some countries suffer more from EP, with a considerable share of the population restricting energy services. At the same time, this situation is mainly concentrated in a small number of households in other nations. A recent study conducted by van Hove, Dalla Longa, and van der Zwaan (2022), carried out at the household level for 11 economically, culturally, and climatically distinct European nations, applied a "low income, high expenditure" approach. In this heterogeneous group of 11 countries, a gradient-boosting classifier[2] was performed on a set of socioeconomic characteristics that are considered predictors of EP.

Other scholars have tried to individuate the dynamics of EP in EU countries. For instance, Rodriguez-Alvarez, Llorca, and Jamasb (2021) proposed a theoretical framework to estimate the EP frontier. According to a country's income level, energy prices, energy intensity, and other country-specific factors, the estimated frontier shows the lowest level of EP the nation may attain. This

[2]Gradient boosting stands out as a preeminent machine learning algorithm, particularly revered for its efficacy in handling tabular datasets. Its robustness extends to discerning intricate nonlinear relationships between the model target and features. Moreover, its practical utility is evident in its adept management of challenges such as missing values, outliers, and high cardinality categorical values in features, all without necessitating specialized treatment.

approach enables one to compare the efficacy of various policy initiatives to reduce poverty among vulnerable people and households. It suggests that financial assistance given to vulnerable people, lower energy costs, and increased energy efficiency have helped tackle EP. In a study of the convergences of EP in 28 EU countries, Huang, Ming, and Duan (2022) found that nations with high levels of EP tend to mitigate it faster than nations with low levels do. As a result, governments must do everything possible to understand the dynamics of EP and to develop long-term policies for its mitigation.

2.1. The issue of the energy poverty index

Regardless of the results obtained until now, the empirical research has usually applied different measures of EP because of the lack of a shared definition of EP itself at the European level (e.g., Dobbins et al. 2019; Faiella and Lavecchia 2021) and the lack of harmonized data to allow spatial and temporal comparisons. For this reason, several indicators and metrics have been suggested in the literature to measure EP, both at the national and European levels (e.g., Gouveia, Palma, and Simoes 2019, Bouzarovski et al., 2021; Macedo, Madaleno, and Moutinho 2022). However, the lack of a single shared measure that can be used to compare different countries has effectively narrowed the scope of analysis, hindering the possibility of direct comparisons of EP value between EU – MS.

A leading article by Castaño-Rosa et al. (2019) underlines the difficulties of proposing a unique EP indicator applicable to all countries because of local peculiarities that make a straightforward approach to measurement complex. For instance, local socio-political factors have been proven to affect the level and persistence of EP (Certomà et al. 2023). Hence, the authors suggested applying a multiple-indicator approach as a starting point for policy decisions to alleviate EP.

A further feature that has emerged in the recent debate centers on the ongoing inflationary trend, especially in energy commodity prices, is the need to reduce extra-EU dependence on fossil fuels by providing strong investments in renewables. In European plans, this approach means minimizing the share of energy generated from traditional fossil sources and accelerating the ET (Gros and Shamsfakhr, 2022; Carfora and Scandurra 2024). The EC's REPowerEU Plan adjusted the objective to reach 45% of the energy generated from renewables by 2030, increasing the planned target set at 30% (EC, 2022). The EC also intends to accelerate the ET emerging from the decoupling of electricity prices from gas prices, which could significantly reduce a household's electricity price, thus facilitating the contrast to EP (Menyhért 2022).

Considering the interpretive framework until now outlined, this study has two aims.

The first aim is to suggest a composite and alternative measure of EP to the existing ones to make possible spatial and yearly comparisons across EU – MS. As shown in the next section, we propose a synthetic index that aggregates individual indicators after statistically identifying the weights based on the well-known method of Principal Components Analysis (PCA). Moreover, we used data from Eurostat's EU – SILC, ensuring mutually comparable data. This method allowed to assess temporal dynamics and compare countries' performances. Respect on the indicator proposed by Thomson and Snell (2013) applying an arbitrary weight system, the indicator we propose in this study adds a further variable. It assigns weights based on the underlying statistical analysis through the PCA procedure. In this way, the limitation of arbitrary assignment of weights can be overcome. Thus, the yearly EP indicator represents the outcome variable of a panel model used to assess how ET affects the dependent variable.

The second aim of this paper is to contribute on the debate about the impact of the ET on EP, verifying whether the ET process assures EP reduction among EU – MS. ET, which involves shifting from traditional fossil-fuel-based energy sources to renewable energy sources like solar, wind, and hydroelectric power, can indeed play a significant role in tackling EP in terms of cost reduction, resilience, and reliability. As recently demonstrated (e.g., Carfora and Scandurra 2024; Zhao et al. 2022), ET deeply contributes to reducing the share of households unable to keep home adequately warm.

Renewable energy technologies have witnessed significant cost reductions over the years, making them more affordable and accessible, particularly for those in low-income communities. This can help alleviate EP by providing cheaper alternatives to expensive fossil fuels (Ram et al. 2018). Moreover, by diversifying the energy mix and incorporating renewables, communities can build more reliable and resilient energy systems, reducing the vulnerability of marginalized populations to energy shortages (Lippert and Sareen 2023).

Furthermore, renewable energy sources can be harnessed locally, reducing dependence on centralized energy grids. This is especially beneficial for remote or rural areas that may not have access to traditional energy infrastructure, reducing energy poverty (Dong et al. 2021).

Verifying this relationship is particularly important because, as mentioned, prices related to energy products have quickly increased in this social and economic period. Hence, driving a solid push to generate systems that reduce energy dependence on fossil sources as well as from countries outside the EU is expected (e.g., Maria-Jose, Merino, and Cairns 2022).

3. Energy poverty

3.1. How energy poverty is measured

EP is widely considered one of the most complex facets of poverty to measure. This is due to the lack of empirical data and the multidimensionality of its implications, which affect several aspects of households' lives. Although extensive, the empirical literature has not proposed an unambiguous method to measure EP. Over time, several measures have been proposed. They can be broadly categorized into three main methods (see, e.g., Sareen et al. 2020; Tirado-Herrero 2017):

- Expenditure Approach: This method examines households' energy costs relative to absolute or relative thresholds. Researchers estimate the prevalence of energy poverty by comparing actual energy expenditures against these thresholds. However, this approach mainly relies on expenditure data and may not fully capture the multifaceted nature of energy deprivation.
- Consensual Approach: In this approach, individuals self-report their indoor housing conditions and assess their ability to meet basic necessities within the context of their society. By considering subjective perceptions, this method provides insights into the lived experiences of energy-deprived households. However, it may be influenced by cultural and social factors.
- Direct Measurement: The approach evaluates the actual energy services achieved within a home, such as heating and lighting. Researchers compare these achieved levels to predefined standards. For instance, internal temperature readings help determine whether households maintain adequate warmth for health and well-being. While this approach provides objective data, it may overlook contextual factors and variations in energy needs.

The direct measurement approach, while valuable, has limitations. It relies on actual energy expenditures rather than considering the required energy needed for a decent standard of living. As a result, it may not fully capture the energy needs of vulnerable households. To overcome this limitation, some authors have modeled the energy expenditure required in the objective indicators (e.g., Antepara et al.
Q4 2020; Barrella et al. 2021).

Because of this heterogeneity, one of the primary challenges in choosing the type of measurement lies in data availability. However, because EP is a multidimensional concept involving a multiplicity of aspects, there is a tendency to ensure that subjective aspects are bypassed in order to converge its measurement toward objective measurements (e.g., Charlier and Legendre 2019). Nevertheless, some researchers acknowledge that subjective measures may have several advantages, such as capturing the "feeling" of material deprivation perceived by individuals (Fahmy, Gordon, and Patsios 2011), as well
Q5 as capturing the intensity of EP, not just its incidence (e.g., Alvarez and Tol, 2020). For this reason, many researchers use the perception of hardship as recorded by the EU – SILC (e.g., Carfora,

Scandurra, and Thomas 2022; Huang, Ming, and Duan 2022; Marchand et al. 2019), which provides an initial, albeit subjective, measure of the degree of energy hardship.

Extensive work has been done by the EPOV observatory, which has proposed a set of four primary and 19 secondary indicators for measuring EP (Thema and Vondung 2020). However, additional difficulty lies in collecting and measuring the relevant data (Thomson, Bouzarovski, and Snell 2017). These indicators have been updated in the Reports proposed by EPAH, the new observatory that replaces EPOV (Gouveia et al. 2023).

Not by chance, to date, there is no coherent framework for collecting and disseminating data on the proposed indicators. Over time, some authors have used a measure that combines subjective and objective aspects (Kahouli 2020; Llorca, Rodriguez-Alvarez, and Jamasb 2020; Munyanyi, Mintah, and Baako 2021; Sokołowski et al. 2020; Waddams Price, Brazier, and Wang 2012) but have found contrasting results.

One of the most popular combination approaches in the literature aggregates three variables using a different weighting system (Thomson and Snell 2013), effectively creating four different measures of EP depending on the weights assigned to the individual variables.

With respect to this approach, in this paper, we adopt a different measurement of the degree of EP of a spatial unit based on the well-known methodology of composite indicators. Although the index proposed by Thomson and Snell (2013) is also composite, the index we suggest in this study uses an aggregation system based on the weighting factors that emerge from a PCA. It is based on the aggregation of the three simple indices already applied i) inability to keep home adequately warm; ii) in arrears on utility bills; and iii) presence of leak, damp, rot in the dwelling to which is also added the share of housing costs in disposable household income. In this way, we obtain a multidimensional measure that escapes the subjectivity of the weights and allows for spatial and temporal comparisons between the indices. We also managed to create a ranking of countries according to EP level.

3.2. The proposed EP indicator

As previously reported, the EU – SILC indicators chosen for the calculation of EP level are the share of:

- families in arrears on utility bills,
- families unable to keep the home adequately warm,
- population living in a dwelling with a leaking roof and/or damp walls,
- housing costs in disposable household income.

The first, second, and third indices are those used for measuring EP by applying the consensual approach proposed by Thomson and Snell (2013). These indices are almost unanimously considered crucial indicators of EP (Aristondo and Onaindia 2018; Halkos and Gkampoura 2021; Primc and Slabe-Erker 2020).

To these indices, we also add the share of housing costs in disposable household income. It intends to represent low-income households that are especially at risk as a large portion (Eurostat in 2023[3] suggests that for people at risk of poverty was 38%) of their income goes toward housing expenses due to this restricts spending on other basics, such as food, health care, and education. This variable is usually considered a key factor in measuring EP (Grdenić, Delimar, and Robić 2020; Karpinska and Smiech 2020; Meyer et al. 2018). Moreover, according to Guio, Fusco, and Marlier (2009), all indicators of housing deprivation are deemed absolute necessities to live a life of good quality and dignity.

We do not consider expenditure-based indicators that, as known, are founded upon the principle of energy consumption affordability. Typically, they juxtapose a reference expenditure measure, such as households' energy expenditure or its proportion to income, against a specific critical threshold. This

[3]https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230216-1

methodology necessitates detailed data on housing conditions, enabling the detection of deviations in energy expenditures from estimated household energy requirements. However, assessing the required consumption quantity (or its associated cost) poses challenges for cross-country comparisons due to the absence of standardized data (Halkos and Gkampoura 2021). Alternatively, methods based on the proportion of energy spending to a predetermined fraction of total household consumption or income overlook the influence of individual preferences and necessities (Miniaci, Scarpa, and Valbonesi 2014; Moore 2012). While more readily available and comparable across nations, these approaches neglect vulnerable consumers lacking access to energy services due to cost constraints or limited availability. Moreover, they are susceptible to including relatively affluent households among those with high energy consumption levels.

The four indicators are then combined in a single index using the methodology of composite indicators (OECD 2008), obtaining a series of EP values for 26 EU – MS along the years 2007–2020. According to the OECD (2008, 15), "A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multidimensional concept that is being measured." A composite indicator has the advantage of allowing the ranking of countries because it represents overall performance in one number.

To remove the scale effect, we normalized the raw data using the min – max method, which can be used in conjunction with all the weighting schemes and for all aggregation systems making directional adjustments in a normalization procedure. Then, to avoid the risk of collinearity among the indicators, we performed the PCA (Saisana 2012).

To combine the indicators in the composite one, we aggregated the weights of each indicator using the geometric means (OECD 2008; Scandurra et al. 2018):

$$EP_{i,t} = \prod_{k=1}^{4} X_{k,i,t}$$

where for each i-EU-MS (i = 1, . . . , 26) in year t (t = 2007–2020), EP indicates the composite indicator for energy poverty while X summarizes the four indicators (k = 1, . . . , 4).

According to the PCA, the weighting process follows the step summarized by OECD (2008). To determine latent factors, we extract factors with eigenvalues exceeding one and include factors with cumulative contributions to overall variance exceeding 60%. Moreover, to maximize the variance of loadings, we employed the varimax rotation. Subsequently, weights are assigned based on the rotated factor loadings matrix. Initially, normalized square factor loadings are calculated, followed by grouping sub-indicators with the highest factor loadings. These sub-indicators are then aggregated, and their composites are weighted proportionally to the explained countries' variance in the dataset.[4]

Next, the obtained indicator was normalized into a range between 0 and 1, with 0 representing the lower incidence of EP and 1 representing the maximum. Given that the simple indices used for construction are subjective, we could name the index as the "perceived energy poverty index" (PEPI).

Table 1 shows the average EP indicator for 26 EU – MS. It also reports the minimum to the maximum values recorded in the time span 2007–2020.

Table 1 clearly shows that some countries, denoted by the low incidence of PEPI (e.g., Austria, Belgium, Estonia, Finland, France, Luxembourg, Sweden), exhibit low variability in their situation. In contrast, other countries with high PEPI (e.g., Bulgaria, Greece, Hungary, Lithuania, Romania) are characterized by a higher variability. Looking at the average values over the period under consideration (Figure 1) reveals that the contrast is related to the heterogeneity associated with the country's income distribution (Carfora, Scandurra, and Thomas 2022).

[4]The results of the composite indicators are based on the R package Compind (Fusco, Vidoli, and Sahoo 2018).

Table 1. Perceived energy poverty index in EU-MS (2007–2020).

Countries	ISO2	Means	Min	Max
Austria	AT	0.21	0.02	0.27
Belgium	BE	0.23	0.14	0.40
Bulgaria	BG	0.78	0.32	1.00
Croatia	HR	0.25	0.08	0.58
Czechia	CZ	0.35	0.04	0.48
Denmark	DK	0.40	0.01	0.70
Estonia	EE	0.20	0.01	0.39
Finland	FI	0.08	0.00	0.19
France	FR	0.19	0.15	0.25
Germany	DE	0.39	0.07	0.65
Greece	EL	0.61	0.31	1.00
Hungary	HU	0.54	0.25	1.00
Ireland	IE	0.08	0.00	0.45
Italy	IT	0.38	0.18	0.67
Latvia	LV	0.59	0.21	0.87
Lithuania	LT	0.64	0.28	0.91
Luxembourg	LU	0.07	0.00	0.20
Netherlands	NL	0.38	0.03	0.62
Poland	PL	0.48	0.21	0.70
Portugal	PT	0.49	0.08	0.79
Romania	RO	0.72	0.33	1.00
Slovakia	SK	0.26	0.07	0.50
Slovenia	SI	0.16	0.00	0.45
Spain	ES	0.20	0.09	0.35
Sweden	SE	0.25	0.06	0.38
United Kingdom	UK	0.35	0.11	0.55
Average		*0.36*	*0*	*1*

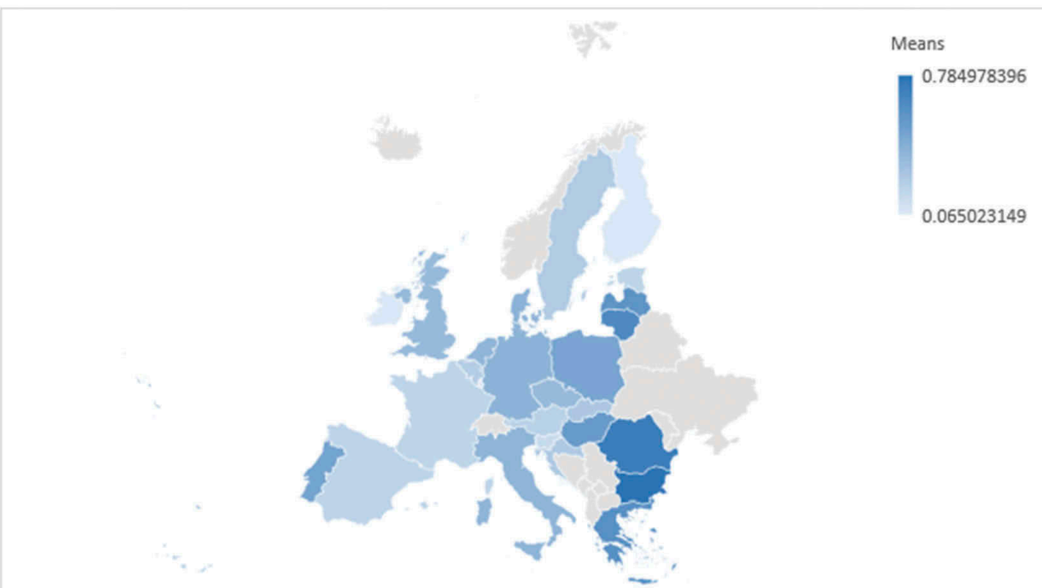
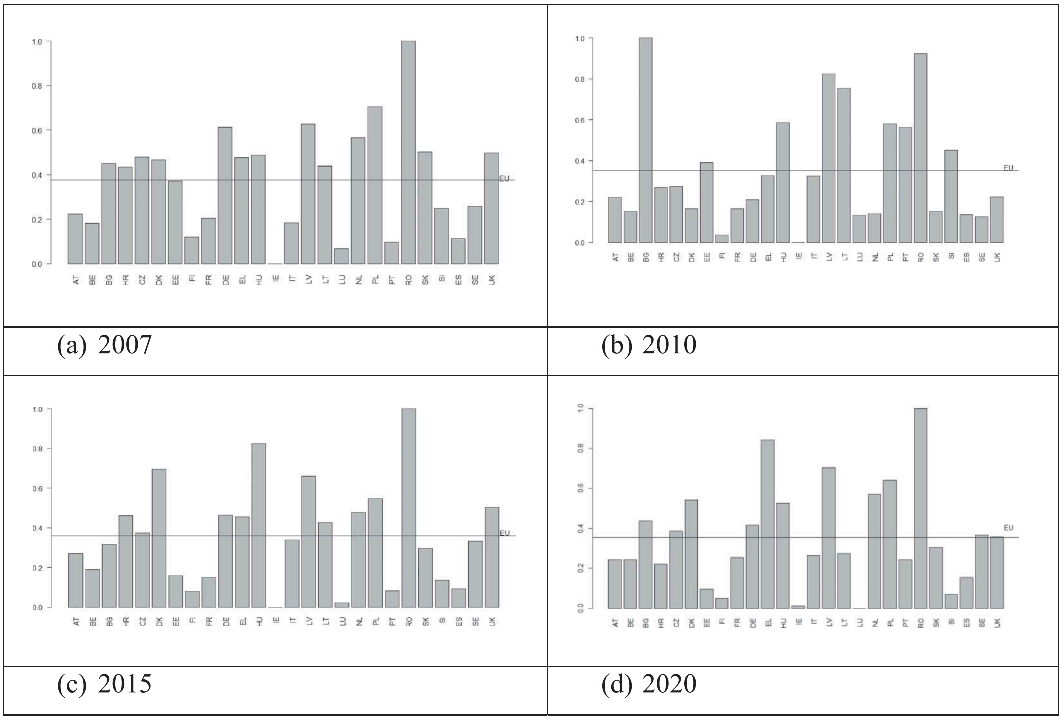


Figure 1. Perceived Energy Poverty Index (PEPI) average distribution in EU-MS.

3.3. *Yearly and spatial comparison of energy poverty in European countries*

After defining an appropriate EP index, we carried out spatial and temporal comparisons among the EU – MS. The indications from this comparative analysis are helpful in indirectly testing whether the actions to



Q34 **Figure 2.** Distribution of EU-MS by PEPI index.

mitigate EP taken by different EU countries have been effective, even considering exogenous factors that have occurred over time, such as economic and/or pandemic crises.

The comparison is shown in Figure 2. The horizontal line represents the average PEPI value and is used as a benchmark. Focusing on this figure and using 2007 (the first year of the available time series) as a baseline, we noted that the PEPI value of the countries exceeding the average PEPI declined in the early years and then increased, in part because of the sovereign debt crisis that began in 2010 and continued in subsequent years and to the 2020 pandemic crisis. We also noted that most countries exceeding the average value are in Eastern Europe (i.e., Bulgaria and Romania). They have a lower degree of development than the European average and have less robust economic fundamentals than the central or northern countries. In addition, social welfare conditions in these countries are traditionally weaker, with lower attention paid to households' energetic distress.

To explore the dynamics of EP in EU – MS, Figure 3 shows the evolution among the countries experiencing a high rate of EP in the time span considered, and Figure 4 shows the same dynamic for the countries with lower levels of EP.

The countries with the highest PEPI index values over the period are the Netherlands, Poland, Romania, Denmark, Greece, Portugal, Bulgaria, Lithuania, Latvia, and Hungary. As can be seen in Figure 3, these countries alternate in the last positions. Some are present for several consecutive years, whereas others have a lower frequency. Countries that show clear evidence of persistence in EP conditions are Bulgaria, Romania, Latvia, and Lithuania. These are joined by Greece, especially in recent years. These are the countries most affected by EP that is due jointly to economic and climatic conditions. The other countries, however, have occupied the last positions in only a few years. They have a lower performance among the countries with the highest degree of EP. This may be due to exogenous factors not considered in the index that cause variability.

Figure 4 shows the countries with a lower incidence of PEPI in the considered years. As shown in Figure 3, some countries persist in this group for only a few years, whereas four (Ireland, Finland,

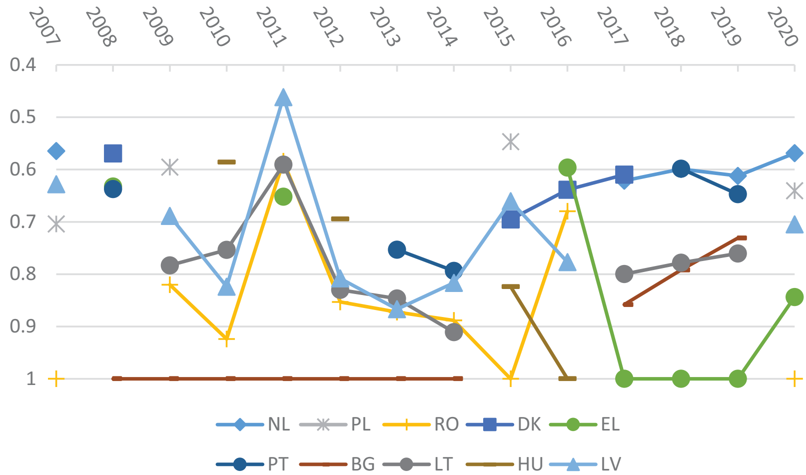


Figure 3. EU-MS with the higher PEPI index. Years 2007–2020.

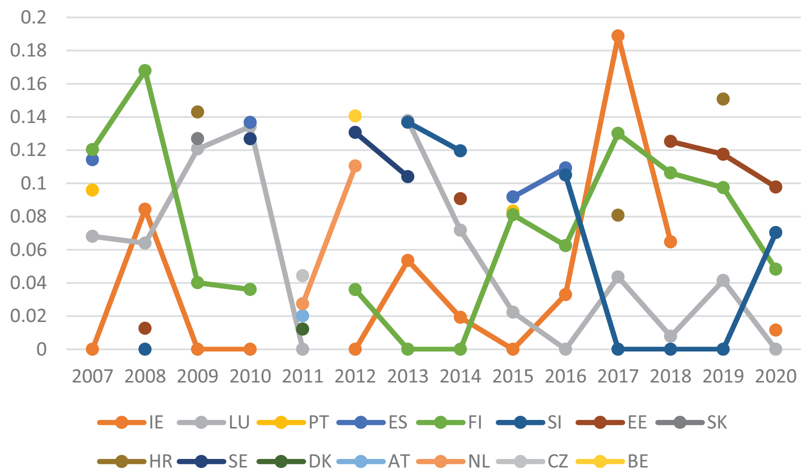


Figure 4. Countries with the lower PEPI index. Years 2007–2020.

Luxemburg, and Slovenia) show temporal persistence, demonstrating a low incidence of EP. These four countries are quite heterogeneous based on different macroeconomic fundamentals and generation systems. Particularly, Luxembourg and Ireland are among the countries with the highest gross domestic product (GDP) per capita.[5] After deeply suffering from the 2008 financial crisis, it is worth noting that Ireland has profoundly improved its GDP and now ranks among countries with the wealthiest economies. In addition, Ireland is investing heavily in renewable generation sources, setting a goal to reach 80% of its Q6 needs by 2030 (DACC, 2021[6]), aiming substantially for energy independence, thanks to the plan called the Renewable Electricity Support Scheme (SEAI Sustainable Energy Authority of Ireland 2019).

As pointed out by a recent article (Castaño-Rosa et al. 2022), the low levels of EP in Finland are considered to be the outcome of housing policies that have promoted the use of energy-efficient building techniques and the utilization of district heating infrastructure. In addition, there are

[5]In the case of a very small country like Luxembourg there could be a discrepancy between the people who contribute to the GDP (often linked to flows of workers from neighboring countries) and the residents who determine the level of EP.
[6]www.gov.ie/en/press-release/f03a4-minister-ryan-welcomes-129-billion-allocation-for-decc-as-part-of-the-ndp-2021-2030-review/

measures to support the social security and welfare of citizens, which the country's politicians have long boasted about.

It is also interesting to highlight the uniqueness of Slovenia. Like the other eastern countries, it has been characterized by low GDP values and an overall underdeveloped economic background over the years. Still, despite these similarities to the countries for which the highest values of EP have been observed, Slovenia has stood, for three consecutive years, as the country with the lowest EP incidence at the European level. Slovenia has a small energy sector in which oil (45%) is the primary energy source. Electricity generation is equally divided among hydropower, nuclear energy, and coal. Energy policy tendencies are moving toward the direction of keeping the status quo. A significant percentage of households that report living in EP have low incomes and inhabit buildings with low energy efficiency (Živčič and Tkalec 2019).

In a nutshell, the dynamic analysis of the proposed indicator provides evidence of some peculiarities of European EP conditions. The most affected countries are in eastern Europe. In contrast, those experiencing it the least are the northern European ones. The causes are obviously due to both economic and housing conditions. Crumbling dwellings, built without following energy-saving principles or with outdated ones, make the discomfort felt the most. The same, of course, is due to economic conditions, which amplify the divergence.

To check the difference between the averages across countries and years, we performed a simple two-way analysis of variance (Table 2). It confirmed a significant difference concerning one of the two main effects. The average PEPI was significantly different at the 1% level among countries. No significant differences in the average yearly PEPI emerged. Consequently, we inferred that the average EP level significantly differs among countries.

This evidence implies that the policies proposed by the decision-makers have been ineffective in tackling EP. Because there is, to date, no shared European action that identifies tools to tackle this scourge, each country tends to act independently and address the issue of EP according to the subjective prominence it attaches to the issue. Moreover, the effect of their action is heterogeneous.

Lack of harmonization of policy measures risks further amplifying divergences in EU development, with more sensitive countries (or those with greater availability of resources) able to affect EP and other countries that not being able to mitigate it, with the risk of increasing social tensions, especially at a historical moment when ongoing inflation has increased energy costs and reduced spending capacity.

4. Determinants of the energy poverty index

In the previous section, we showed that the heterogeneous EP incidence in EU – MS involves synthesizing four variables. The proposed EP index (PEPI) overcomes some of the limitations of the commonly used measures. In our opinion, this approach ensures the well-known data quality requirements essential for developing synthetic measures, especially for aggregate comparisons over time and space.

The uncertainty associated with energy supply sources and the ongoing inflationary movement, especially concerning commodities, has led the EU to accelerate the progressive replacement of generation sources, facilitating and simplifying the transition to renewable sources. The aim, therefore, is to see whether the ET can help alleviate EP in EU – MS. To this end, a panel data model has been developed to study the relationship between the transition and EP while controlling for the incidence

Table 2. Two-way anova test.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Country	25	14.160	0.5664	19.355	0.000
Year	1	0.018	0.0182	0.623	0.431
Residuals	337	9.862	0.0293		

of several social, economic, and housing factors, which may be additional levers on which to act to effectively counteract the share of struggling households in EU – MS. The use of a model with panel data, by blending the both interindividual and intra-individual differences, has several advantages over cross-sectional or time-series data (Hsiao 2007):

- more accurate inferences about model parameters,
- greater capacity for capturing the complexity of human behavior,
- capacity to uncover dynamic relationships and control the impact of omitted variables,
- simplified computation and statistical inference.

4.1. Selection of variables

To reach the second aim of this paper, we first consider ET and electricity prices. As the ET process concerns the gradual replacement of fossil fuels with renewable or green sources, it can be expressed as the difference between the share of electricity produced from renewable sources and the share of energy from fossil sources. In this way, it is possible to capture the substitution of generation sources because it is of a relative magnitude corrected for the effect of increased generation due to investment and/or technical progress. Electricity price is one of the leading causes of EP, especially for vulnerable Q7 consumers. Llorca et al. (2018) suggested that the combination of high energy prices and low GDP represents the main drivers of EP.

Moreover, Bagnoli and Bertoméu-Sánchez (2022) pointed out that consumers tend not to change their consumption when prices decrease after implementing economic support measures. However, the recent inflationary crisis has reignited the debate between energy price and EP. For this reason, we also consider the price of electricity for household consumers.

The demography of the region, the house features, and the characteristics of families (composition and size) all have a substantial impact on EP (Imbert, Nogues, and Sevenec 2016; Miniaci, Scarpa, and Valbonesi 2014; Sareen et al. 2020), as do discrepancies in technological and socioeconomic conditions (McLean et al. 2019). For these reasons, we include various control variables in the model specification.

Among the socioeconomic variables, we include the people at risk of poverty or social exclusion (*pov*) (Njiru and Letema 2018); the GDP index (*gdp index*; 2010 = 100), the percentage of the population with low educational attainment *(educ %)* (Omar and Hasanujzaman 2021; Oum 2019), and the availability of childcare services (*child*) (Arlington et al. 2019). The average number of rooms per person (*rooms*) and degree of urbanization summarize the house features. However, we do not consider the age of housing, although it is plausible that newer dwellings adopt more consistent construction criteria with heat loss.

Because the scientific literature (e.g., Santamouris 2016) shows that a territory's climatic conditions and geography affect EP, we include heating degree days (*heating*) by country to sum up the climatic characteristics of the nations. The heating degree day index is a weather-based technical indicator designed to describe the need for the heating energy requirements of buildings.[7] Obviously, it is lower in countries that benefit on average from many days of sunshine and higher temperatures.

Variables, definitions, and data sources are listed in Table 3.

4.2. The model

To estimate the effect of ET on EP, we developed a panel model. The basic representation of the model proposed is

[7]Metadata and technical issues relating to the development of the index are available at https://ec.europa.eu/eurostat/cache/metadata/en/nrg_chdd_esms.htm

Table 3. Variables, definitions and data sources.

Variable	Definition	Source
gdp_index	Gross domestic product at market prices - Chain linked volumes, index 2010=100 [nama_10_gdp]	Eurostat
Heating	Heating degree days	Eurostat
Elprices	Electrical energy prices in purchasing power standards	Eurostat
Pov	People at risk of poverty or social exclusion by age and sex [ilc_peps01]	Eurostat – EU-SILC survey
Educ	Population by educational attainment level, sex and age (%) - main indicators [edat_lfse_03]	Eurostat
Rooms	Average number of rooms per person by tenure status and dwelling type from 2003 onwards - EU-SILC survey [ilc_lvho03]	Eurostat
Cities	Distribution of population by degree of urbanization, dwelling type, and income group - EU-SILC survey [ilc_lvho01]	Eurostat
Child	Children in formal childcare or education by age group and duration - % over the population of each age group - EU-SILC survey [ilc_caindformal]	Eurostat
Trans	Difference between the share of Renewable generation and the share of fossil generation (%)	Elaboration
Health	Healthy life years by sex (from 2004 onwards) [hlth_hlye]	Eurostat
Gini	Gini coefficient of equivalised disposable income - EU-SILC survey [ilc_di12]	Eurostat – EU-SILC survey

$$\mathrm{EP_{it}} = \mathrm{f}(gdp_{it}, heating_{it}, elprice_{it}, poverty_{it}, education_{it}, rooms_{it}, cities_{it}, child_{it}, trans_{it}, health_{it}, gini_{it}), \tag{1}$$

where subscripts i and t are the cross-sectional unit (country) and time unit (year), respectively.

We can rewrite Equation 1 as follows:

$$\mathrm{EP_it} = \beta_0 + \beta_1 elprice_{it} + \beta_2(Sh\_ren_{it} - Sh\_Fossil_{it}) + \sum\nolimits_{k=3}^{K} \beta_k X_{it} + \varphi_t + \omega_t + \varepsilon_{it}, \tag{2}$$

where $elprice_{it}$ is the electricity price, $(Sh\_ren_{it} - Sh\_Fossil_{it})$ is the proxy for the ET; X_{it} contains all the control variables; φ_t denotes the time effects; ω_t represents the individual specific effects; and ε_{it} indicates the random disturbance term, which is assumed to be independently and identically distributed (*i.i.d.*).

The main descriptive statistics and stationarity tests are listed in Table 4. The last columns of the table report the value of the statistics associated with unit root tests.

Due to the similarities among EU – MS, the results could be affected by cross-sectional correlations, so we tested for the presence of contemporaneous correlation using the Pesaran CD and Breusch and Pagan LM tests (Table 5).

Both tests failed to accept the null result of no cross-sectional correlation in the model's residuals. The presence of contemporaneous correlation in the panel suggests that a suitable model should be used to consider the cross-correlation (or contemporaneous correlation).

Table 4. Descriptive statistics and unit root tests.

Variable	Obs	Mean	Std. Dev.	Min	Max	Im-Pesaran Shin (p-value)	Lin, Levin, Chu test (p-value)	CIPS test-statistics
gdp_index	364	107.76	12.74	77.31	187.41	0.0000	0.0000	−2.80**
Heating	364	2952.29	980.41	1007.58	6179.75	0.0000	0.0000	−3.535***
Elprices	364	1928327	0.04	0.10	0.30	0.0000	0.0155	−2.454***
Pov	364	23.91	7.70	11.9	60.7	0.0043	0.0000	−3.662***
Educ	364	25.95	7.65	9.9	42.8	0.1636	0.0000	−2.78**
Rooms	364	1.62	0.41	0.9	2.4	0.0000	0.0000	−2.88***
Cities	364	38.02	10.84	13	75.9	0.0135	0.0000	−3.010***
Child	364	19.02	14.89	0	69	0.0000	0.0000	−3.056***
Trans	364	−61.34	22.92	−96.53	20.25	0.0643	0.0017	−2.75**
Health	364	60.86	6.21	0	73.3	0.0000	0.0000	−2.326**
Gini	364	29.93	3.95	20.9	40.8	0.0001	0.0002	−2.851**
EP	364	0.36	0.26	0	1	0.0000	0.0000	−2.71**

: significant at 5%; *: 1%.

Table 5. Cross-correlation test.

Test	z-value	p-value
Pesaran CD	4.2998	1.71e-05
Breusch Pagan LM	24.338	0.000

Considering that the test highlights the presence of contemporaneous correlation, we used the Pesaran Panel Unit Root Test in the Presence of Cross-Section Dependence (Pesaran 2007). We also added the statistics associated with two other commonly used stationarity tests: (1) the Im, Pesaran, and Shin test (Im, Pesaran, and Shin 2003) and (2) the Lin, Levine, and Chu test (Levin, Lin, and Chu 2002). The results failed to accept the null hypothesis of a unit root in the variables.

Once we discarded the presence of unit root, we also controlled for collinearity among the variables (Table 6). Both the Variance Inflation Factor (<5) and Tolerance (>0.10) suggested that the explanatory variables are non-collinear, confirming the adequacy of the variables selected.

Considering the presence of a cross-correlation between panel and heteroscedasticity across panels, it is possible to use two different estimators: i) feasible generalized least squares and ii) panel-corrected standard errors. As Beck and Katz (1995) suggested, the former produces valid estimates when the number of periods are greater than the number of units. In our case, the number of periods is lower than the number of units. So, we prefer to estimate the relationship using the latter estimators. Table 7 reports the estimates of the parameters in Equation 2.

The estimated coefficients are mostly significant and consistent with the expected sign. We observe, that ET can be considered as a lever on which to act to tackle EP. Transitioning to renewable energy sources can reduce dependency on fossil fuels, stabilize energy prices, and lower energy costs over time, making energy more affordable for households. Moreover, the shift to renewable energy sectors can create new job opportunities, potentially increasing household incomes and reducing poverty levels.

Table 6. Collinearity statistics.

Variable	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
Poverty	3.68	[3.12, 4.38]	1.92	0.27	[0.23, 0.32]
Elprice	1.40	[1.26, 1.63]	1.19	0.71	[0.61, 0.79]
gdp_index	1.40	[1.26, 1.63]	1.19	0.71	[0.61, 0.79]
Trans	1.76	[1.55, 2.05]	1.33	0.57	[0.49, 0.65]
Heating	2.23	[1.93, 2.62]	1.49	0.45	[0.38, 0.52]
Rooms	4.13	[3.49, 4.93]	2.03	0.24	[0.20, 0.29]
Educ	3.25	[2.77, 3.86]	1.80	0.31	[0.26, 0.36]
Gini	3.21	[2.73, 3.81]	1.79	0.31	[0.26, 0.37]
Occ	1.50	[1.34, 1.75]	1.23	0.66	[0.57, 0.75]
Child	1.88	[1.65, 2.20]	1.37	0.53	[0.45, 0.61]
Health	1.22	[1.12, 1.42]	1.11	0.82	[0.70, 0.89]

Table 7. Estimation results.

Variable	Coefficient	Std. Err	z	P>|z|
Constant	0.064	0.164	0.39	0.699
Poverty	0.012	0.003	4.60	0.000
Elprice	0.681	0.374	1.82	0.068
gdp_index	−0.003	0.001	−2.40	0.016
Trans	−0.001	0.001	−2.26	0.024
Heating	0.00007	0.00003	2.32	0.020
Rooms	−0.218	0.055	−4.00	0.000
Educ	−0.007	0.004	−2.00	0.045
Gini	0.006	0.007	0.84	0.400
Child	−0.003	0.001	−2.51	0.012
Health	0.002	0.001	1.43	0.154
Cities	0.005	0.001	3.15	0.002

In addition, the rising price of electricity increases EP in EU – MS. Focusing on the control variables, we observe that they are all significant except for healthy life years and the Gini index.

4.3. Robustness check

To check the consistency of the proposed indicator and the results obtained, we estimated the same models but changed the target variable; specifically, we used the EP measure proposed by Thomson and Snell (2013) as the target variable[8] and divided it into the four scenarios summarized in Table 8. In literature, numerous indices measure EP (e.g., Costa-Campi, Jové-Llopis, and Trujillo-Baute 2019; Rosa et al. 2020; Sokołowski et al. 2020; Davillas et al., 2021), but they are generally developed for specific countries or territorial areas. They encapsulate the characteristics inherent in the studied territory and can leverage data that allow for micro-spatial analysis.

Many proposed indices are based on an objective or expenditure approach, disregarding subjective aspects. Nevertheless, aggregated analyses concerning entire countries require a shared database containing comparable data on specific elements. Currently, as is known, EU-SILC enables such analyses at the European level, and the aggregated data, albeit subjective, allow for the study of EP distribution. With data extracted from EU-SILC, it is easy to construct Thomson and Snell's index extremely straightforwardly. The estimates are in Table 9.

The estimated coefficients of the four different specifications, which use the multiple indicators proposed by Thomson and Snell (2013) as outcome variables, compared with the benchmark specification previously reported in Table 7, show no substantial changes in significance and signs. In particular, focusing on the variables related to ET and energy commodity prices reveals that they are always significant and consistent in sign. Few differences were found among the control variables. This result can be judged satisfactory, both for the robustness of the model and the adequacy of the selected explanatory variables.

Table 8. Weighting scheme of alternative EP indicators.

Indicator	Weights
EP(2)	0.5**enpov*+0.25**arrears*+0.25**housedep*
EP(3)	0.25**enpov*+0.5**arrears*+0.25**housedep*
EP(4)	0.25**enpov*+0.25**arrears*+0.5**housedep*
EP(5)	0.33**enpov*+0.33**arrears*+0.33**housedep*

Table 9. Estimation results with the alternative EP indicators as dependent variables.

	Dependent variable			
Variable	EP(2)	EP(3)	EP(4)	EP(5)
gdp_index	−0.040***	−0.051***	−0.007	−0.033***
heating	−0.001 ***	−0.001***	−0.001***	−0.001***
Pov	0.792***	0.798***	0.664***	0.744***
educ	0. 062**	0.164***	0.027*	0.083***
health	0.017	0.007	−0.004	0.007
rooms	−5.296***	−6.711***	−6.259***	−6.028***
Gini	−0.028	−0.273***	−0.106	−0.134*
cities	−0.008	−0.041***	−0.019*	−0.022**
child	−0.010	0.008	−0.005	−0.002
trans	−0.015***	−0.022***	−0.008***	−0.015***
elprice	−8.571***	−13.800***	−9.865***	−10.638***
_cons	7.481***	19.435***	10.545***	12.362***

Significant at: *** 1%; ** 5%; *10%.

[8]Thomson and Snell (2013) suggest aggregating the following index: inability to keep home adequately warm (*enpov*); ii) arrears on utility bills (*arrears*); and iii) presence of leak, damp, rot in the dwelling (*housedep*).

5. Discussion

The research pattern underlying this study is based on the proposal of a composite indicator to measure the incidence of EP in EU – MS and how EP is affected by ET and electricity price changes. These aspects are particularly important at this historical stage, which is marked by a strong inflationary trend in energy commodity prices and the European Community's pressures to accelerate the ET.

The dynamic analysis of the proposed indicator showed in section 3 lets us underline specific features of EP conditions in Europe. This analysis, based on the synthesis of variables collected by the EU – SILC survey that ensures harmonized, and therefore comparable, data at the European level, makes it possible to highlight the evolution of EP among EU – MS. In particular, the analysis of the indicators revealed the heterogeneity present among European countries, which are marked by a different incidence of EP, summarized by the proposed indicator. Most of the nations in Eastern Europe are experiencing the most energy-related strain. The northern European countries, on the other hand, have the lowest levels. The causes most likely stem from the state of the economy and the housing market. Old homes, or homes that were not built with energy-saving techniques, are where the hardship is felt the most (Mulder, Dalla Longa, and Straver 2023). A similar effect is caused by macroeconomic factors accentuating the discrepancy regarding EP level.

With specific reference to the second aim, how ET affects EP, we observed that accelerating ET makes easier tackling EP in EU – MS. Consistent with Hasheminasab, Streimikiene, and Pishahang (2023), incentivizing the use of renewable sources among countries can contrast the diffusion of EP. This result is particularly significant because accelerating alternative energy production as opposed to fossil fuels tends to determine higher costs, at least in the initial stages, partly because of the new infrastructure investments (e.g., Araújo 2014). The advantage is the possibility of minimizing the energy security problem, which is more marked in times of economic crisis (Cox 2016), such as the present period. However, we have to specify that although energy security is an ambiguous term, with many competing and contradictory definitions, it "does not necessarily arise as a problem in EU public policy. This incongruence between science and policy is not a problem per se. Academia has different interests than policy, and what can be interesting from a research perspective (conceptualizing an ambiguous term) may not be a priority in policymaking" (Kovacic and Di Felice 2019, 165). Overall, while the ET holds the potential to alleviate EP in the long term through sustainable energy practices and economic opportunities, careful policy planning and targeted support measures are essential to ensure that vulnerable populations benefit from these changes.

Confirming the outcomes of Rodriguez-Alvarez, Llorca, and Jamasb (2021), this investigation also points out a direct relationship between electricity prices and EP. Hence, when energy prices rise, people's living conditions tend to worsen because the prices directly affect the share of households entering EP. It is thus confirmed that the current cycle, marked by high inflation and driven precisely by the sharp increase in energy commodity prices, pushes people to reduce their energy consumption with the same disposable income (Sovacool 2012).

Negative effects on the level of EP also come from increasing numbers of households living in poverty or worsening climatic conditions. These findings were largely expected because the lower availability of monetary resources and purchasing power leads us to consider the ability to heat up (or cool down) as a subjective need of a lower order than other primary needs, such as nutrition or health. It is not by chance that the national GDP exerts a direct and positive effect on alleviating EP (Halkos and Gkampoura 2021). Although it is not always true in reality, we can assume that when a country's GDP grows, an improvement in the per capita income and employment level, with wider purchasing power for consumers is likely to occur.

Conversely, social-type variables, such as the average number of rooms per person and number of children in formal childcare, have a negative relationship with EP; a rising change in these variables reduces EP. Regarding the number of rooms, the results reported in the literature are contradictory. Some scholars argue that larger homes are colder than smaller ones, mainly because of the incidence of energy bills (Hamilton et al. 2017; Sharma, Han, and Sharma 2019), whereas others highlight that households with larger homes are less vulnerable to EP (Abbas et al. 2020). One explanation for this relationship is that householders do not always purchase the house where they live by themselves based on their income, as they could have received it by inheritance or marriage, and in other cases, people are living in a house that was purchased when they were in a better economic situation (this is the case for pensioners or widowers who must now survive without the income of the deceased spouse).

Similarly, there is no precise correspondence between large families and income levels. After all, recent studies have shown that demographic and socioeconomic factors influence EP (Lowans et al. 2023). EP also suffers from greater spatial concentration than income poverty, thus widening the social and economic inequalities that characterize, in particular, the most backward areas of Europe. These areas, as well known, also coincide with the countries where the incidence of EP and the economic level of development are lower (Koďousková and Bořuta 2022).

Other relevant variables are those related to the urbanization. In line with previous studies (Roberts
Q9 et al., 2015; Rodriguez et al., 2022), we observed a direct relationship between the variables summariz-
Q10 ing urbanization and EP. In practice, a higher level of urbanization moves countries away from a virtuous path of EP reduction. In addition, a very recent article by Pereira and Marques (2023) highlighted that energy alternatives (oil, wood/biomass, natural gas, and electricity) have differing impacts on EP in areas with different levels of urbanization. In support of this finding, it should be remembered that in rural areas, energy costs are often lower, or there are more sources of supply (e.g., stoves and fireplaces that use coal or pallets or wood that are impossible to use in urban areas), as well as a greater ease in resorting to alternative sources, such as wind or solar energy because of wider spaces (Yadav, Malakar, and Davies 2019). However, other studies also underlined that rural areas are more vulnerable to EP (Dokupilová and R 2021; Ren et al. 2022).

6. Conclusions

In recent years, Energy Poverty (EP) has become an increasingly relevant issue at the European level. Several directives to address this problem have been proposed by European Countries (EC) and transposed by European countries. Meanwhile, the green energy transition (ET) has recently been accelerated due to the economic crisis and the Russia – Ukraine war, which involves one of the European countries' major fossil fuel suppliers.

With this in mind, this study aims to pursue two connected aims. Firstly, it proposed a new EP index based on the indicators available in the European Union Statistics on Income and Living Conditions (EU – SILC) survey. Although many indicators have been proposed (e.g., Kelly et al. 2020; Rosa et al. 2020; Villalobos, Chávez, and Uribe 2021), this new index extends the index proposed by Thomson and Snell (2013) and, more importantly, frees the measurement of EP from the arbitrary assignment of weights, making it based on the statistical methodology of Principal Components Analysis (PCA). The analysis made it possible to highlight some features of the incidence and distribution of EP among EU – MS.

Secondly, the study investigated the impact on EP caused by ET and the increase in energy commodity prices. This correlation has not been widely deepened by scientific literature.

The dynamic investigation of the proposed indicator reveals that European Union Member State (EU – MS) with a higher level of EP are mainly those in Eastern Europe; the countries where this problem is less evident are those in the north of Europe. The motives in the different housing conditions that penalize eastern countries for the highest presence of dilapidated dwellings make it easier for the EP to manifest its effect. Another reason is linked to the traditional lower levels of welfare states ensured by the governments of these countries, which have fewer resources to spend in this direction.

Regarding the second aim, the estimated model shows that, to counteract EP in EU – MS, policies should first continue to incentivize ET and try to reduce the prices related to energy sources. The incidence of EP is affected by the inflationary movement, progressively making families' access to energy sources more expensive. According to the International Energy Agency, the pre-Russian – Ukraine war increase in energy prices was due to the post-pandemic economic recovery, increased demand, and an unusually low supply due to a cold and long winter season. These unfavorable weather conditions led to less wind power and low gas storage levels in Europe. The international tensions have greatly affected gas prices, to which the retail electricity price is currently tied. Of course, the goal of reducing prices should aim not only to increase the consumption of energy resources but also to stimulate the purchase of more efficient (energy-saving) and less polluting devices. On the contrary, a worsening in the level of pollution related to increased consumption would be presumable.

However, until now, the EU has tried to counter this effect by introducing a control mechanism on the maximum gas prices, the so-called *price cap*,[9] but this has yielded an apparent result that, as often happens, derives from compromises that safeguard the interests of some parties but do not produce decisive effects for families. At the end of 2022, the climatic conditions made it possible to keep a high level of gas stocks with a beneficial effect on prices, but these advantages could be rapidly reabsorbed with a change in climatic conditions, with a predictable adverse effect on households. The wider diversification of generation sources is also beginning to affect prices positively.

This investigation has some limitations. The first of these comes from the finding that few European countries have defined the issue of EP, and this occurrence creates a patchwork that makes an analytical comparison of the incidence of EP among countries challenging (Dobbins et al. 2019). Moreover, although the proposed index is based on harmonized data that ensure comparability, it should be expanded to include objective measures. This is the second limitation we want to overcome by including in our research agenda the pursuit of additional measures that currently are unavailable or do not ensure data quality requirements.

6.1. Policy implications

The proposed index for measuring EP appears to perform sufficiently well, demonstrating results consistent with those of other indices, and aligned with the statistics on EP from various previous studies. This consistency highlights the urgent need for a single harmonized index at the European level. Such an index should enable reliable spatial and temporal comparisons and address the well-known issue of data availability currently limiting this potential. However, to make this index effective, the concept of EP must be univocally defined. As mentioned in the initial sections, this unified understanding is currently lacking, and each country attributes a different meaning to EP.

The outcomes related to the effect of ET over EP demonstrate that ET processes offer a clear and effective means of alleviating EP, consistent with recent studies (e.g., Kozcak, Ulug, and Oralhan 2023). Hence, policies finalized to promote ET are justified and should be enforced. The European Green Deal, approved in 2020 by the European Commission, aims to achieve climate neutrality by 2050. This policy is well-suited to increase renewable energy generation while simultaneously reducing EP in European countries. The European Green Deal addresses multiple aspects, including building renovation and the security of energy supplies, to tackle EP and ensure a fair ET.

The study also shows that the two primary factors contributing to EP are the high incidence of income poverty and external shocks driven by unforeseen events outside the EU that have caused a strong inflationary spiral in energy prices. These factors mainly affect families in older homes lacking adequate environmental protection. With this in mind, subsidizing building renovations and energy adaptations could yield greater long-term benefits than acquiring advanced devices, which tend to increase energy consumption. Although this measure is economically demanding, it is slow to exhibit immediate effects. Moreover, investing in energy self-sufficiency and accelerating renewable sources

[9]The two main EU agencies (ACER and ESM) that oversee the financial and energy markets have just declared (January 2023) that, so far, the price cap has not had a significant impact on the price of gas, although without excluding the possibility that it could have a momentum in the future.

would help stabilize and control energy prices in the medium term, reducing vulnerability to external shocks and speculation.

The study also confirms that the different levels of EP among EU countries exacerbate internal inequalities. Mainly, Eastern European countries, which generally experience harsher climates than Mediterranean countries, are the most affected by winter EP. Addressing this issue requires more policies than the aforementioned ones.

The study also confirms that GDP has a direct and positive effect on mitigating EP, suggesting the necessity of accelerating economic development in these regions to increase disposable incomes. This goal is aligned with the EU's founding principles, which promote uniform development through various instruments, such as cohesion funds, that likely need strengthening. Given the lengthy nature of development processes, in the meantime providing monetary and fiscal incentives and subsidies to support building renovations that increase energy efficiency and develop clean energy systems appears essential. Direct subsidies to larger families with a higher tendency toward EP should also be considered for equity and energy justice reasons.

However, it is essential to acknowledge that accelerating ET could present new financial challenges. Fossil fuels currently represent a significant source of fiscal revenue for European countries, funding investments in renewable sources. Thus, accelerating ET will require greater economic commitment from governments and potentially reduced tax revenues. To compensate for the loss of fiscal revenue and to finance the necessary investments for the energy transition, the economic policy authorities of some European countries, such as Italy, are considering the possibility of introducing mandatory contributions to be included in electricity bills. Although driven by the need to identify resources without burdening the State budget, this approach risks further compromising the conditions of families, especially the most vulnerable ones, thus nullifying the efforts made to tackle EP.

On all these aspects, a robust response from the European Commission is expected, capable of balancing budgetary needs, tackling EP, and boosting the ET. This contribution provides some suggestions on these issues, but it is evidently up to the policymakers to identify the best strategies for energy policies.

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ORCID

Giuseppe Scandurra http://orcid.org/0000-0003-4261-8928

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