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# Evaluating the energy poverty in the EU countries

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ABSTRACT

The domain of energy poverty is increasingly recognised as a multifaceted global challenge stemming from limited income, high energy costs, and inefficient housing. The issue affects different social groups and regions unevenly, even within Europe. This paper investigates energy poverty across 32 economies, including EU member states and several non-EU European countries, over the period from 2004 to 2021. By analysing micro-level data from the EU-SILC database and Eurostat, the study identifies that low-income households, smaller households, and those living in overcrowded conditions are particularly vulnerable to energy poverty. Interestingly, the research finds that renewable energy does not contribute to alleviating energy poverty in Europe. Based on these results, the study calls for immediate policy measures to improve housing conditions and lower electricity costs, especially for economically disadvantaged households, to effectively address energy poverty.

## 1. Introduction

Energy poverty has recently attracted increasing attention from researchers and policymakers and is now acknowledged as a significant global challenge. This importance is highlighted by its inclusion as the seventh goal of the Sustainable Development Goals (SDGs), which aims to ensure universal access to affordable, reliable, sustainable, and modern energy services. Although there is no universally agreed-upon definition, energy poverty typically refers to inadequate physical access to clean and modern energy in developing countries. In contrast, in developed countries, it mainly manifests as an affordability issue known as fuel poverty (Buzar, 2007; Bonatz et al., 2019). Primc et al. (2021) reviewed literature from the past three decades to examine the similarities and differences within and between these definitions.

Energy poverty is often viewed through a socioeconomic lens, with the European Union (EU) defining it as the inability of individuals or households to afford the energy required for essential activities such as heating, cooling, lighting, cooking, and other vital tasks (Bonatz et al., 2019). Various factors contribute to energy poverty, including high energy costs, poor energy efficiency, inadequate housing, income inequalities, societal influences, and policy and regulatory challenges. A recent literature review by Siksnelyte-Butkiene (2021) found that most scholars assessed four groups of indicators: energy price, income, energy demand, and building energy efficiency. The review concluded that energy poverty is linked to economic factors as well as social and environmental considerations.

The impacts of energy poverty are wide-ranging and significant, affecting health, well-being, education, and the economy while also raising environmental concerns (Banerjee et al., 2021; Apergis et al., 2022; Katoch et al., 2023). Those experiencing energy poverty endure poor comfort and sanitary conditions, such as uncomfortably hot or cold indoor temperatures, low air quality, and exposure to hazardous substances and materials. These conditions lead to reduced productivity, health issues, and increased mortality rates (Phoumin and Kimura, 2019; Pan et al., 2021; Ballesteros-Arjona et al., 2022; Lee and Yuan, 2024). Unaffordable energy bills also cause significant psychological stress for those affected by energy poverty (Thomson et al., 2017; Zhang et al., 2021; Koomson, 2024). Castano-Rosa et al. (2019) conducted a comprehensive analysis of existing concepts and indicators of fuel poverty, as well as current initiatives to address this issue across Europe. This has sparked discussions on how factors contributing to energy vulnerability, such as available infrastructure, energy efficiency, social and economic deprivation, and well-being and health, align with fuel poverty scenarios.

Addressing energy poverty necessitates a multifaceted strategy that integrates governmental intervention, community participation, and private sector engagement. Key measures to combat energy poverty include enhancing energy efficiency, implementing financial aid

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initiatives, improving access to renewable energy, reforming policies, addressing socioeconomic disparities, and empowering communities. By addressing the root causes and impacts of energy poverty, societies can promote equity, enhance public health, and support sustainable development.

Despite extensive research focusing on energy poverty in developing countries through the analysis of socioeconomic and household-level factors, there remains a significant knowledge gap concerning the situation and drivers of energy poverty in developed countries (Ben Cheikh et al., 2023). This study seeks to bridge this gap by providing insights into energy accessibility and affordability in developed nations. Specifically, it aims to contribute to the ongoing discourse on the socio-economic factors influencing energy poverty from a household-level perspective across a diverse array of developed countries, including both EU and non-EU nations. To this end, the study employs fixed-effect regression models and household-level micro panel data from the EU-SILC database and Eurostat to identify the determinants of energy poverty in European and some non-European countries.

Previous research on energy poverty has typically concentrated on individual countries or small groups of countries, and studies encompassing the majority of EU countries over an extended period are rare (Kryk and Guzowska, 2023). A recent study by Halkos and Gkampoura (2021) indicated that, among 28 European countries analysed, only the Scandinavian countries are free from energy poverty. This study focuses on EU countries for several reasons, as they share common characteristics that make them particularly vulnerable to energy poverty. These include a significant lack of energy-efficient building infrastructure, living standards, and the widespread issue of high emissions from the combustion of solid fuels in households.

The impacts of energy poverty are far-reaching, influencing health, well-being, education, and the economy, while also raising environmental concerns (Banerjee et al., 2021; Apergis et al., 2022; Katoch et al., 2023). Those affected by energy poverty experience poor living conditions, such as extreme indoor temperatures, low air quality, and exposure to hazardous substances, leading to reduced productivity, health issues, and higher mortality rates (Phoumin and Kimura, 2019; Pan et al., 2021; Ballesteros-Arjona et al., 2022; Lee and Yuan, 2024). High energy bills also cause significant psychological stress for those experiencing energy poverty (Thomson et al., 2017; Zhang et al., 2021; Koomson, 2024). Castano-Rosa et al. (2019) conducted a comprehensive analysis of existing concepts and indicators of fuel poverty and current initiatives to address this issue across Europe. This analysis has sparked discussions on how factors contributing to energy vulnerability, such as infrastructure availability, energy efficiency, social and economic deprivation, and well-being and health, align with fuel poverty scenarios.

While the significance of employing microeconomic data from individual households is well-recognised, such data are relatively scarce in the literature (Agbim et al., 2020; Simshauser, 2021; Mulder et al., 2023). Additionally, many studies tend to emphasize aggregated national averages, which, although offering a broad perspective, often fail to capture the intricate experiences of energy poverty faced by various demographic or socioeconomic groups within a population. By leveraging microeconomic data, this study goes beyond the surface-level insights provided by national averages, enabling a more detailed examination of the disparities in energy poverty within countries. When available, these datasets typically focus on a single country or region (Antunes et al., 2023). Thus, this study aims to address the existing gap in the literature by integrating household-level data with national-level information, creating a comprehensive analytical framework for a more nuanced understanding of household-level variations across different countries. This approach not only enriches the current literature but also provides valuable insights that can inform policy strategies focused on reducing energy poverty and improving the socioeconomic conditions of households.

The structure of the paper is as follows: Section 2 outlines the European Union's measures for addressing energy poverty. Section 3 reviews the literature on energy poverty in developed countries. Section 4 describes the dataset and methodologies employed. Section 5 presents the empirical results, while Section 6 discusses the main findings. Finally, Section 7 provides policy recommendations to mitigate energy poverty in the EU and suggests directions for future research.

## 2. EU efforts in addressing energy poverty

Addressing energy poverty is imperative due to concerns surrounding energy supply security, escalating energy costs, and the ongoing transition towards carbon neutrality. Ensuring equitable access to energy resources is also essential for fostering a more just and sustainable global community.

Despite its status as one of the wealthiest regions worldwide, Europe continues to confront significant challenges related to energy poverty, impacting a substantial portion of its population. Approximately 50 million households within the European Union currently lack access to adequate essential energy services and are thus experiencing energy poverty.[1] The energy crisis that began in 2021, compounded by the COVID-19 pandemic and Russia's invasion of Ukraine in February 2022, has exacerbated the vulnerability of European households to energy poverty. In response, the EU has prioritised addressing this issue through a range of legislative and non-legislative measures. The energy sector of the Lisbon Treaty significantly influenced the development of the Third Energy Package (TEP), enacted in 2009, which introduced the concept of energy poverty. Both the original Electricity Directive (2009/72/EC) and the Gas Directive (2009/73/EC)—the former of which has been repealed—explicitly addressed this issue. These directives mandated that EU member states create national action plans or frameworks to combat energy poverty, define "vulnerable customers," and implement protective measures, including social security systems and limitations on the disconnection of gas and electricity services.

Enacted in 2019, the "Clean Energy for All Europeans" package, also referred to as the fourth energy package, involved a thorough reassessment of EU energy legislation, encompassing issues such as energy poverty. This review concentrated on key directives including the Electricity Directive, the Energy Efficiency Directive, and the Energy Performance of Buildings Directive. A significant enhancement was the obligation for member states to evaluate the scope of energy poverty within their populations. The revised Electricity Directive mandates that member states develop methods to assess energy poverty, track affected households, and submit their findings to the European Commission every two years. This directive also aims to improve consumer access to information and facilitate the process of switching energy suppliers.

The Energy Efficiency Directive (2012/27/EU, amended in 2021) requires member states to integrate specific measures targeting energy efficiency for households in energy poverty within their Energy Efficiency Obligation Schemes. Additionally, the Energy Performance of Buildings Directive (2010/31/EU), recently updated by Directive (EU) 2018/844 and revised in 2021, requires EU nations to formulate long-term renovation strategies to be included in their national energy and climate plans. While the Gas and Electricity Directives focus on safeguarding vulnerable consumers, the Renewable Energy Directive (EU) 2018/2001, though not directly addressing energy poverty, aims to increase the availability of renewable energy sources for low-income and at-risk households.

In October 2020, the European Green Deal introduced the Renovation Wave Strategy, which seeks to advance the renovation of both residential and commercial buildings to combat energy poverty. This strategy provides guidelines for effective measurement of energy poverty, encourages the exchange of best practices among member

[1] https://www.odyssee-mure.eu/publications/policy-brief/european-energy-poverty.html (accessed July 10, 2024).

states, and identifies opportunities for EU funding targeted at vulnerable communities. For example, the Social Climate Fund prioritises households suffering from energy poverty as key recipients of financial support. The Fit for 55 package, adopted in July 2021, put forward targeted measures to identify primary factors contributing to energy poverty, such as high energy costs, limited household income, and inefficient infrastructure. This package also addresses structural solutions to mitigate vulnerabilities and address systemic inequalities, including a proposal to amend the Energy Efficiency Directive to intensify efforts against energy poverty. Additionally, the 2021 proposal for a revised Energy Taxation Directive introduces provisions for specific tax reductions and exemptions to alleviate the financial burden of energy taxes on vulnerable households.

Moreover, the 2021 revision of the Energy Taxation Directive introduces specific tax reductions aimed at alleviating the societal impact of energy taxes, along with tax exemptions designed to protect vulnerable households. The European Union regulates energy markets to ensure fair pricing and accessibility for all consumers, particularly those at risk of energy poverty. This includes implementing strategies such as price regulation, tariff management, and consumer protection policies to prevent energy poverty and maintain affordability for disadvantaged households.

The EU also invests in the development of innovative technologies and solutions to address energy poverty. This includes funding projects that enhance energy efficiency, promote renewable energy sources, and support social innovations that provide affordable and sustainable energy services to marginalised communities. Programs such as minimum income schemes, social housing projects, and welfare benefits for low-income families play a crucial role in reducing the financial strain of energy costs.

The establishment of the EU Energy Poverty Observatory was driven by the need for better data and understanding of energy poverty across the EU. It serves as a central resource for collecting and sharing information, best practices, and tools related to energy poverty (European Commission, 2023). By providing vital insights and data, the Observatory aids in the formulation of policies and strategies aligned with the goals of the third energy package. Launched in 2021, the Energy Poverty Advisory Hub builds on the work of the EU Energy Poverty Observatory and represents the EU's primary initiative for addressing energy poverty and supporting a fair energy transition throughout Europe. In April 2022, the Commission Energy Poverty and Vulnerable Consumers Coordination Group was established to offer support and develop guidelines for households facing energy poverty and other vulnerabilities. Concurrently, the Social Climate Fund has designated households in energy poverty as its main beneficiaries. EU member states have also developed and implemented targeted measures and methodologies for measuring and monitoring energy poverty to effectively address this issue.

## 3. Literature review

While a definitive consensus on the precise definition of energy poverty remains elusive, the growing body of research underscores its significance as a multifaceted socio-economic and environmental challenge. This recognition highlights the urgent need for comprehensive and targeted strategies to address energy poverty effectively. A notable study conducted by Scarpellini et al. (2015), which analysed 615 households experiencing energy poverty in Spain's Aragón region, emphasised that responsible authorities must understand the underlying factors driving energy poverty and its severity in specific contexts to implement appropriate and tailored interventions. Researchers have explored various dimensions of this complex issue, examining its origins, impacts, and potential solutions while considering variables such as household income, energy consumption patterns, living standards, and access to energy services.

The task of evaluating energy poverty (EP) is intricate due to its reliance on multiple household-specific factors, including income, consumption behaviours, specific energy needs, and available technologies, as well as external influences such as energy prices, climatic conditions, and the energy efficiency of buildings. This complexity has led to the development of a range of EP measurement metrics, both single and composite, designed to capture the phenomenon from various angles. These indicators predominantly focus on economic factors, though social and environmental considerations are often incorporated in a more indirect manner. A comprehensive review of composite indicators for measuring energy poverty is provided by Siksnelyte-Butkiene et al. (2021), highlighting the diversity and breadth of approaches in the field.

Despite the expanding research and growing awareness of energy poverty, a unified and clear strategy for addressing this issue within the EU remains absent, as noted by Castano-Rosa et al. (2019). The approach to tackling energy poverty—encompassing both affordability and availability—varies significantly depending on each country's level of development, unique needs, aspirations, and living standards. In the current global economic context, an increasing number of European countries face challenges related to the affordability of energy services, affecting a rising number of households, as observed by Scarpellini et al. (2015).

In their longitudinal study of energy poverty in Spain from 2004 to 2015, Aristondo and Onaindia (2018a) concentrated on three key indicators of energy accessibility: the adequacy of home heating, arrears on utility bills (including electricity, water, and gas), and the presence of structural deficiencies such as leaking roofs, damp walls, or inadequate windows. Aristondo and Onaindia (2018b) further employed these indicators to investigate intra-group variations in energy poverty across Spain, finding that it is particularly prevalent in less densely populated areas and among vulnerable households. A more recent framework developed by Hasheminasab et al. (2023) integrates aspects of accessibility, affordability, and sustainability into the energy poverty paradigm. This framework was applied to 27 EU countries over the period from 2015 to 2020, revealing that energy consumption is a critical factor within the energy poverty framework.

In advanced economies, the economic crisis is a prominent factor exacerbating energy poverty and potentially escalating it into an energy security concern (Dagoumas and Kitsios, 2014). Papada and Kaliampakos (2016) examined energy poverty among 400 households in Greece during the economic downturn, utilising both objective and subjective indicators. Their findings highlighted disparities between these measurement approaches, indicating that individuals with limited incomes or those living in detached houses, colder climates, and higher altitudes are more prone to experiencing energy poverty. In a similar vein, Ntaintasis et al. (2019) applied a range of indicators to assess energy poverty in Attica, Greece, revealing inconsistencies between traditional subjective and objective measures, with minimal correlation observed between the two. The studies conducted by Marchand et al. (2019) and Burlinson et al. (2021) investigated the connection between energy poverty and financial strain in the UK, demonstrating that financial difficulties exacerbate the severity of energy poverty. Halkos and Gkampoura (2021) examined the impact of the economic crisis on energy poverty across 28 European countries from 2004 to 2019, employing consensual methods and composite indicators. Their analysis indicated that higher GDP per capita is linked with lower levels of energy poverty, underscoring the significant impact of the economic downturn on energy poverty in Europe.

Additionally, natural disasters and major accidents have been identified as factors contributing to energy poverty. Okushima (2016) illustrated how energy poverty among low-income and vulnerable households in Japan intensified over the past decade due to rising energy costs and decreasing incomes, with energy prices emerging as a primary driver of energy poverty following the 2011 East Japan earthquake. Furthermore, Okushima (2017) evaluated energy poverty in Japan from a multi-dimensional perspective, noting the considerable impact of increased energy prices after the Fukushima nuclear disaster, particularly on vulnerable populations and the elderly. The COVID-19 pandemic has also been recognised as exacerbating energy poverty, as highlighted by Streimikiene (2022) and Carfora et al. (2022). Other research has explored the intersection of energy poverty with factors such as ethnic diversity (Awaworyi Churchill and Smyth, 2020), racial inequality (Wang et al., 2021), and the effects of trade and globalisation (Zhao et al., 2022a, 2022b).

A substantial body of research focuses on understanding and quantifying energy poverty through the examination of socioeconomic and household-level factors. These studies often centre on specific countries or geographic regions, providing insights into the diverse manifestations of energy poverty (Acharya and Sadath, 2019; Zhang et al., 2019; Lowans et al., 2023; Mulder et al., 2023). For instance, Bollino and Botti (2017) analysed energy poverty across European countries for the years 2012 and 2014, identifying key contributors such as low income, dwelling type, residential location, and population density. Their research further indicated that women and migrants are disproportionately affected by energy poverty, whereas older individuals tend to experience it to a lesser degree.

Employing fuzzy-set qualitative comparative analysis, Primc et al. (2019) developed energy poverty profiles for 150 households in Slovenia, revealing a complex interplay of socio-demographic and housing-related factors influencing energy poverty. Expanding the scope, Primc and Slabe-Erker (2020) investigated energy poverty at a macro-level within the European Union, focusing on policy measures, energy costs, and household income. Their analysis highlighted that energy poverty arises from significant interdependencies, which can be broadly categorised into two pathways: one characterised by low to median household incomes with an emphasis on energy policy, and another marked by high energy prices and a similar focus on energy policy. They observed that EU member states experiencing high rates of energy poverty often prioritise energy policy, yet this focus does not always produce effective outcomes. The authors noted that the scale and cost of addressing energy poverty frequently hinder the implementation of social policies designed to alleviate the issue.

Karpinska and Śmiech (2020a, 2020b) assessed the extent of hidden energy poverty in households across Poland and 11 Central and Eastern European countries, revealing the pervasive nature of the issue in these regions. Abbas et al. (2021) explored the socioeconomic determinants of energy poverty in six South Asian countries, concluding that targeted improvements in household conditions through effective policies could significantly reduce multidimensional energy poverty. Rodriguez-Alvarez et al. (2021) utilised country-level data to examine energy poverty in 30 European countries, finding that fluctuations in energy prices and decreased energy efficiency adversely affect vulnerable populations. Antunes et al. (2023) investigated energy affordability both across and within 26 European countries, emphasising the need for a cohesive policy framework to implement comprehensive solutions. Their study underscored the importance of enhancing energy efficiency in housing and addressing affordability challenges exacerbated by energy and climate crises.

This study intends to significantly enhance the existing body of research on energy poverty by leveraging a comprehensive and multifaceted dataset. This dataset is distinctive in its integration of extensive socioeconomic variables, detailed environmental factors, and data on energy resources. By analysing this information from both a broad national perspective and a granular individual household level, the research aspires to provide a more nuanced and thorough understanding of energy poverty. It aims to uncover the underlying causes of energy poverty and assess its impacts across diverse socio-economic and environmental contexts, thus contributing valuable insights to the field.

## 4. Methods

This research entailed the use of fixed-effect regression models in conjunction with household-level micro panel data to identify the factors impacting energy poverty within European countries. The dataset employed is a cross-country panel, which provides two key sources of variation: (a) variations between different households and (b) temporal variations across different years. This dual approach enables the study to capture and analyse the evolving dynamics of energy poverty over time and across various households.

### 4.1. Variables and data

This study utilised household-level panel data from the EU Statistics on Income and Living Conditions (EU-SILC)[2] a comprehensive dataset provided by Eurostat and collected through the national statistical offices of EU member states. The EU-SILC aims to gather timely and comparable data on various facets such as income, poverty, social exclusion, and living conditions, offering both cross-sectional and longitudinal insights into individuals as well as households.[3] The dataset is harmonised across the EU, facilitating the development of an energy poverty profile for multiple countries. We employed the most recent dataset available, supplemented by country-level variables not included in the EU-SILC to account for national differences (as detailed below).

While primarily covering EU member states, the EU-SILC also includes data from several non-EU European countries, totalling 32 nations. The countries included in this study are Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (GR), Hungary (HU), Iceland (IS), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), the Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Serbia (RS), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), Switzerland (CH), and the United Kingdom (UK).

The dataset spans from 2004 to 2021, although the coverage varies by country. For instance, Austria's data extends from 2004 to 2021, while the Netherlands begins from 2005, and Croatia starts from 2010. This results in an unbalanced panel. The total number of observations across all countries is 4,296,444 (household × year). However, due to some households having only single-year observations, the final number of observations used in our analyses is smaller. Specifically, the dataset includes 1,014,632 households, with Spain contributing the highest number of observations (77,051) and Malta the fewest (9940). Fig. 1 illustrates the percentage of energy poverty[4] based on country, showing that Bulgaria has the highest rate at 46.1 %, whereas Norway has the lowest at 0.8 %. There are notable disparities between emerging European countries, such as Bulgaria, Latvia, and Cyprus, and more advanced nations like the Nordic countries—Finland, Luxembourg, Sweden, and Norway.

Fig. 2 illustrates the annual average percentages of energy poverty, while Fig. 3 depicts the trends in income and employment across 32 countries from 2004 to 2021. A notable decrease in energy poverty has been observed since 2013, likely due to the strict European policies introduced to address this problem, either directly or indirectly. This decline in energy poverty can primarily be attributed to rising income levels and improved employment rates over the years, as illustrated in Fig. 3. When the EU economy grows, marked by rising income levels and increasing employment rates, there is often a corresponding decrease in energy poverty. As the economy expands, individuals and households generally see an increase in their disposable income, providing them with greater financial flexibility to afford essential services like energy, which may have been a previous burden. Employed individuals are also more inclined to invest in energy-efficient appliances and home

[2] The details can be obtained here:https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions

[3] This study makes use of only household-level data.

[4] This energy poverty is measured by "ability to keep home adequately warm", a question in the EU-SILC (see details below).

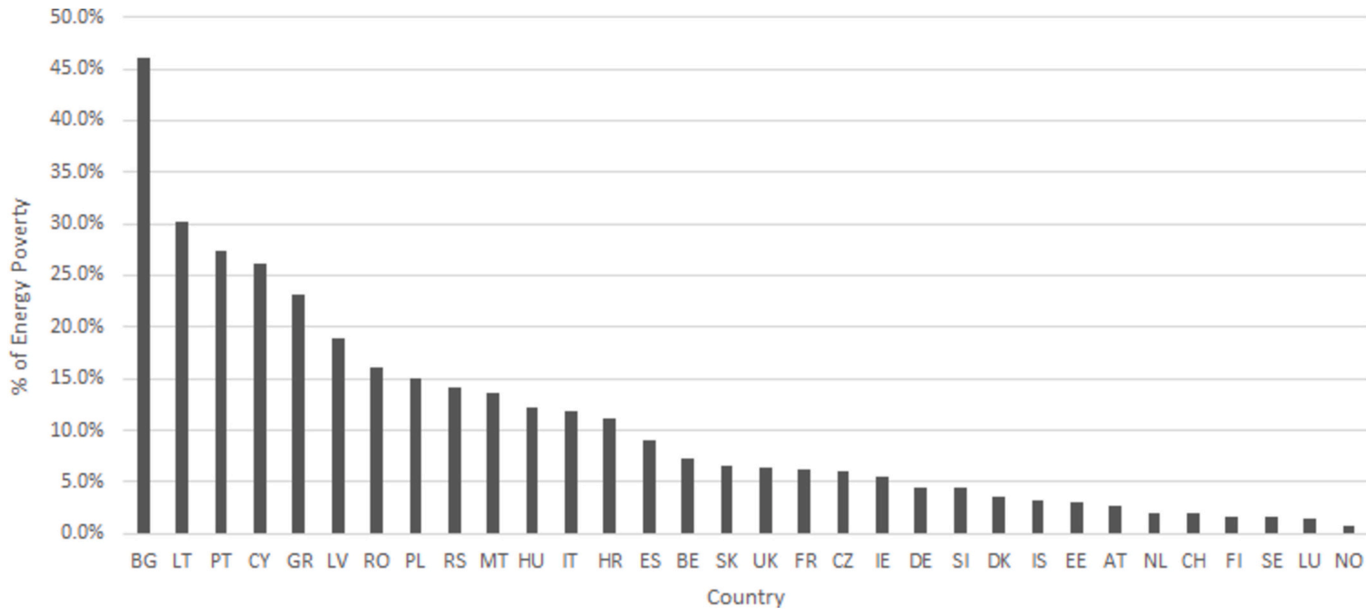


**Fig. 1.** The average energy poverty percentage per country (calculated based on the aggregating observations across all years).

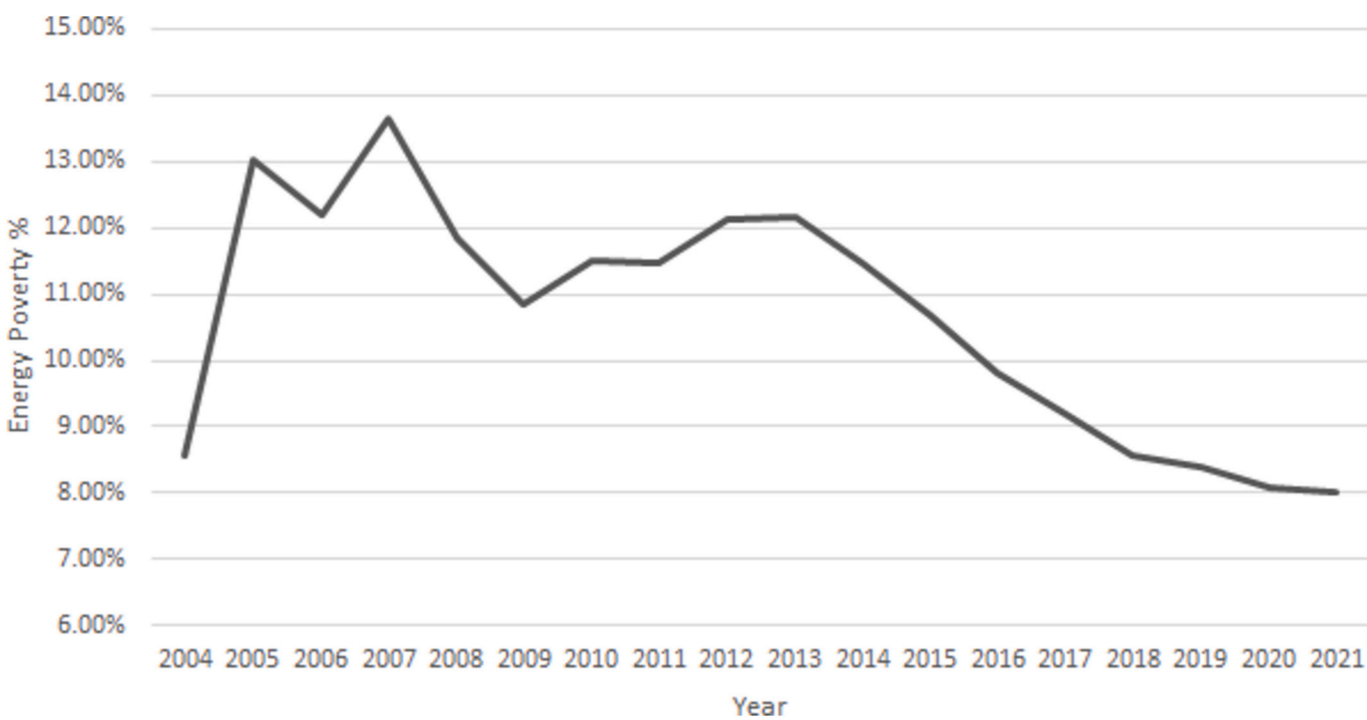


**Fig. 2.** The average percentage of energy poverty over the annual period from 2004 to 2021, calculated from the aggregate data of all the examined countries.

improvements that can lower energy costs over time.

In academic research, various variables or indicators have been utilised as proxies for measuring energy poverty (see Section 3). Some studies rely on single indicators, while others employ composite indicators developed from multiple variables. Although the EU-SILC survey does not specifically measure energy poverty due to the lack of a unified EU definition, it does capture several relevant aspects. This study selected a suitable variable from the EU-SILC dataset to assess energy poverty, based on the EU's elucidation,[5] the "ability to keep home adequately warm (*Warm*)", utilising it as the dependent variable. As far as the EU-SILC database is concerned, this variable is derived from a question commonly phrased, though with slight variations in wording across member states.: "Is your household able to afford to adequately heat its home?". A household is deemed to be experiencing energy poverty if it answers negatively ("no") to the question about the ability to keep their home adequately warm. This implies that the household

[5] https://energy.ec.europa.eu/topics/markets-and-consumers/energy-consumer-rights/energy-poverty_en

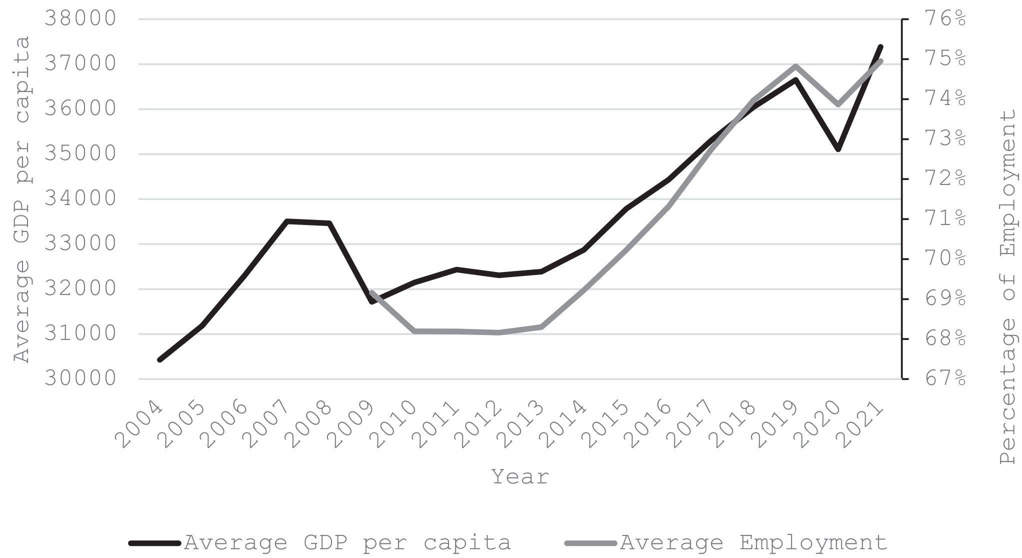


**Fig. 3.** The average GDP per capita and percentage of employment (employment data for the countries analysed is available starting from 2009) over the annual period from 2004 to 2021, calculated from the aggregate data of all the examined countries.

cannot afford the necessary expenditure on heating (whether through electricity or other fuels) if they lack the means to do so. This accessibility measure gauges the proportion of households that lack the financial resources to maintain a comfortable indoor temperature. It has been widely utilised in both national and comparative research on energy poverty across Europe.

The EU-SILC dataset provides a comprehensive array of variables. The cross-sectional household files encompass information on various elements, including household characteristics, income, housing conditions, and regional factors, among others. Specifically, these independent variables comprised "dwelling type (*Dwelling*)", "degree of urbanisation (*Urbanisation*)", "tenure status (*Tenure*)", "leaking roof, damp walls/floors/foundation, or rot in window frames or floor (*Leaking*)", "number of rooms available to the household (*Room*)", ""ability to make ends meet (*Meet*)", arrears on mortgage or rent payments (*Mortgage*)", "pollution, grime or other environmental problems (*Pollution*)", "noise from neighbors or from the street (*Noise*)", "crime violence or vandalism in the area (*Crime*)", "total disposable household income (*Income*; EUR/year)", "equivalised household size (*Size*)", "overcrowded household (*Crowd*)", and "regular taxes on wealth (*Wealth*: EUR/year)", as well as "household type (*Type*)" (also refer to Table 1). Additionally, country-level independent variables were incorporated to account for differences between countries. These variables, which are consistent for all households within the same country and year, were introduced to control for national-level variations. These include: "cooling degree days (*CDD*: °C)", "heating degree days (*HDD*: °C)," "share of renewable energy (*Renewable*)," "electricity price (*ElectricityPrice*: EUR)," "Gross Domestic Product (GDP) per capita (*GDP*: USD)," "employment rate (*Employment*)," "greenhouse gas emissions by source sector (*GHG*: million tons)". The country-level data is predominantly sourced from Eurostat, with the exception of *GDP* figures, which are retrieved from the World Development Indicators provided by the World Bank).[6]

Several studies have established connections between various indicators such as GDP, employment rates, electricity prices, and the share of renewable energy and energy poverty (Halkos and Gkampoura, 2021). Notably, GDP per capita has been identified as a significant predictor of a household's capacity to maintain sufficient warmth, while electricity prices have been recognised as a major contributor to energy poverty, with higher prices typically exacerbating the issue. Additionally, the presence of leaks in homes has frequently been utilised as an indicator of energy poverty in numerous studies (Ntaintasis et al., 2019; Kryk and Guzowska, 2023).

Although research on the relationship between energy poverty and renewable energy is relatively sparse, existing studies suggest that increased use of renewable energy sources could potentially mitigate energy poverty (Nduka, 2021; Zhao et al., 2022a, 2022b). The variables chosen for this study are also in alignment with several United Nations SDGs, particularly Goal 7, which addresses all facets of energy poverty, including both accessibility and affordability. Realising this goal requires comprehensive household-level analyses using income and expenditure data, which is the primary aim of this research. In cases where country-level data were not available, we used a dataset encompassing 32 countries to provide estimates, while a more restricted dataset was employed where country-level data were present. Table 1 presents the descriptive statistics for these variables.

Because *Income* includes "cash benefits or losses from self-employment," the values can be negative.

### 4.2. Empirical strategies

This research examines the factors influencing energy poverty across European countries by employing household-level panel data. To achieve this, we utilised a linear regression model that incorporates fixed effects for both households and survey years. This approach allows us to control for unobserved heterogeneity within households and account for temporal variations across different survey years, thereby providing a more accurate analysis of the determinants of energy poverty.

$$Y_{ht} = \alpha + X_{ht}\beta + \lambda_h + \mu_t + \upsilon_{ht}, \tag{1}$$

where $h$ and $t$ signify the household and survey year, respectively, $Y_{ht}$ denotes an indicator of energy poverty, whereas $X_{ht}$ represents a vector of observed household- and country-level variables as outlined in Section 4.1 Meanwhile, the vector of coefficients is denoted by $\beta$. At the same time, the model encompasses household fixed effect $\lambda_h$ as well as survey year fixed effect $\mu_t$, which control for unobserved household characteristics and annual variations, respectively. By incorporating both household and time-fixed effects, we can derive more accurate

[6] https://databank.worldbank.org/source/world-development-indicators

**Table 1**
Descriptive statistics of the selected variables.

| Variable | Observation | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| *Warm* | 4,288,839 | 0.103 | 0.303 | 0 | 1 |
| *Urbanisation*: 1 | 3,857,927 | 0.389 | 0.488 | 0 | 1 |
| *Urbanisation*: 2 | 3,857,927 | 0.260 | 0.439 | 0 | 1 |
| *Urbanisation*: 3 | 3,857,927 | 0.350 | 0.477 | 0 | 1 |
| *Dwelling*: 1 | 4,188,198 | 0.397 | 0.489 | 0 | 1 |
| *Dwelling*: 2 | 4,188,198 | 0.189 | 0.391 | 0 | 1 |
| *Dwelling*: 3 | 4,188,198 | 0.150 | 0.357 | 0 | 1 |
| *Dwelling*: 4 | 4,188,198 | 0.264 | 0.441 | 0 | 1 |
| *Tenure*: 1 | 4,293,628 | 0.748 | 0.434 | 0 | 1 |
| *Tenure*: 2 | 4,293,628 | 0.147 | 0.355 | 0 | 1 |
| *Tenure*: 3 | 4,293,628 | 0.048 | 0.214 | 0 | 1 |
| *Tenure*: 4 | 4,293,628 | 0.057 | 0.231 | 0 | 1 |
| *Room* | 4,225,265 | 3.788 | 1.410 | 1 | 6 |
| *Leaking* | 3,994,248 | 0.843 | 0.364 | 0 | 1 |
| *Mortgage* | 1,977,220 | 0.060 | 0.238 | 0 | 1 |
| *Meet* | 4,253,335 | 3.361 | 1.358 | 1 | 6 |
| *Noise* | 3,980,639 | 0.824 | 0.381 | 0 | 1 |
| *Pollution* | 3,980,224 | 0.862 | 0.344 | 0 | 1 |
| *Crime* | 3,978,086 | 0.882 | 0.322 | 0 | 1 |
| *Size* | 4,294,926 | 1.670 | 0.588 | 1 | 11.5 |
| *Crowd* | 3,543,967 | 0.133 | 0.340 | 0 | 1 |
| *Income* | 4,295,494 | 29,337.730 | 35,454.640 | −2,574,420 | 12,900,000 |
| *Wealth* | 3,854,477 | 204.661 | 741.627 | 0 | 290,136 |
| *Type*: 5 | 4,294,926 | 0.264 | 0.441 | 0 | 1 |
| *Type*: 6 | 4,294,926 | 0.151 | 0.358 | 0 | 1 |
| *Type*: 7 | 4,294,926 | 0.163 | 0.369 | 0 | 1 |
| *Type*: 8 | 4,294,926 | 0.091 | 0.288 | 0 | 1 |
| *Type*: 9 | 4,294,926 | 0.039 | 0.192 | 0 | 1 |
| *Type*: 10 | 4,294,926 | 0.089 | 0.285 | 0 | 1 |
| *Type*: 11 | 4,294,926 | 0.102 | 0.303 | 0 | 1 |
| *Type*: 12 | 4,294,926 | 0.037 | 0.190 | 0 | 1 |
| *Type*: 13 | 4,294,926 | 0.061 | 0.239 | 0 | 1 |
| *Type*: 16 | 4,294,926 | 0.004 | 0.060 | 0 | 1 |
| *HDD* | 3,949,034 | 2844.253 | 1164.315 | 322.36 | 6205.66 |
| *CDD* | 3,949,034 | 110.405 | 149.874 | 0 | 812.18 |
| *ElectricityPrice* | 4,161,515 | 0.172 | 0.054 | 0.0586 | 0.32135 |
| *Renewable* | 4,042,662 | 19.942 | 14.049 | 0.177 | 77.358 |
| *Employment* | 3,249,730 | 70.222 | 7.268 | 52.5 | 87.8 |
| *GHG* | 4,104,726 | 198.032 | 234.464 | −1.46746 | 1003.211 |
| *GDP* | 4,296,444 | 32,709.830 | 20,195.420 | 5462.735 | 112,417.9 |

Notes: For the binary variables, yes = 1 and no = 0. *Urbanisation*: 1 densely populated area, 2 intermediate area, 3 thinly populated area; *Dwelling*: 1 detached house; 2 semi-detached or terraced house; 3 apartment or flat in a building with less than 10 dwellings; 4 apartment or flat in a building with 10 or more dwellings; *Tenure*: 1 Owner, 2 Tenant or subtenant paying rent at prevailing or market rate, 3 Accommodation is rented at a reduced rate (lower price that the market price), 4 accommodation is provided free; *Type*: 5 One person household, 6 2 adults, no dependent children, both adults under 65 years, 7 2 adults, no dependent children, at least one adult 65 years or more, 8 Other households without dependent children, 9 Single parent household, one or more dependent children, 10 2 adults, one dependent child, 11 2 adults, two dependent children, 12 2 adults, three or more dependent children, 13 Other households with dependent children, 16 Other (these household are excluded from Laeken indicators calculation).

estimates of the relationships under investigation. This approach filters out the unobserved heterogeneity related to households and time, thereby enhancing the robustness of our results. It does so by concentrating on the variations within each household over time and among different households during the same time periods. The error term is represented by $\upsilon_{ht}$. Standard errors in the fixed effects estimations are clustered by household and survey year.

To begin with, we conducted estimations using a specific set of household-level variables. This was followed by further analyses that incorporated additional variables, including those at the country level. Given that the dependent variable is binary, we also applied a logistic regression model to extend our analysis. In these logit model analyses, we included the same variables as in the linear regression models and maintained fixed effects for both households and survey years to account for variations across these dimensions.

## 5. Results

This section outlines the results from the linear regression models, with details on the logistic regression models provided in the Appendix.

Table 2 summarises the key findings. Positive coefficients suggest an increase in energy poverty. All independent variables included in the analysis are statistically significant. Economic indicators show that households with lower incomes and fewer assets are more susceptible to energy poverty. Housing conditions also play a role; for instance, smaller households, those with fewer rooms, leaking roofs, or overcrowding are more likely to face energy poverty. A higher ratio of rooms per person in a household often signifies greater wealth, which may lead to less severe impacts from energy poverty compared to households with fewer rooms per person. This could be because wealthier families can afford larger homes and are less likely to encounter problems like leaks, dampness, or rot.

The surrounding environment, encompassing factors such as *Noise*, *Pollution*, and *Crime*, is recognised as a significant contributor to energy poverty. The likelihood of experiencing energy poverty is higher for households residing in adverse environmental conditions, with the extent of urbanisation also playing a role in worsening the problem. Conversely, the *Dwelling seems to ameliorate energy poverty.*

Table 3 presents the results from the fixed-effect regression analysis, which includes additional independent variables, both at the household and country levels. The table features different specifications of the models. In these analyses, some variables from the previous model were

**Table 2**
Main result utilising the fixed-effect linear regression model.

| | (1) *Warm* |
|---|---|
| *Urbanisation:* densely populated area | 0.012*** (0.001) |
| *Urbanisation*: intermediate area | 0.011*** (0.001) |
| *Dwelling*: semi-detached or terraced house | −0.008*** (0.002) |
| *Dwelling*: apartment or flat in a building with less than 10 dwellings | −0.021*** (0.001) |
| *Dwelling*: apartment or flat in a building with 10 or more dwellings | −0.028*** (0.001) |
| *Tenure*: Tenant or subtenant paying rent at prevailing or market rates | 0.015*** (0.001) |
| *Tenure*: Accommodation is rented at a reduced rate | 0.027*** (0.003) |
| *Tenure*: accommodation is provided free | 0.028*** (0.001) |
| *Room* | −0.002*** (0.001) |
| *Leaking* | −0.086*** (0.001) |
| *Meet* | −0.068*** (0.001) |
| *Noise* | −0.007*** (0.001) |
| *Pollution* | −0.013*** (0.001) |
| *Crime* | −0.022*** (0.001) |
| *Size* | −0.029*** (0.001) |
| *Crowd* | 0.021*** (0.001) |
| *Income (/1,000,000)* | −0.048** (0.013) |
| *Wealth (/1000)* | −0.003* (0.001) |
| Constant | 0.500*** (0.007) |
| Observations | 2,511,940 |
| Adjusted R-squared | 0.191 |

Notes: The base of Urbanisation is "thinly populated area," that of Dwelling is "detached house," and that of Tenure is "owner." *** denotes statistical significance at the 0.1 % level, ** denotes statistical significance at the 1 % level, and * denotes statistical significance at the 5 % level. The analysis includes household and year fixed effects. The values in the parentheses are clustered-robust standard errors.

replaced; for example, *Poverty* was used instead of *Income*. The findings for household-level variables are similar to those in Table 2, although fewer variables are statistically significant in this expanded model. Economic factors, including new variables such as *Mortgage* and *Poverty*, are statistically significant at the 0.1 % level, indicating that households in poorer economic conditions are more likely to face energy poverty. Additionally, households with substandard housing conditions and a challenging environment are more prone to energy poverty. However, the effects of temperature, represented by HDD and CDD, are not clearly delineated, possibly due to regional temperature variations within countries.

When households are classified by type, "households with two parents and dependent children" show less vulnerability to heating their homes, whereas "one-person household" is more susceptible compared to "single parent household, one or more dependent children." Although single-person households are frequently associated with higher vulnerability, some studies indicate that families with dependent children and larger households are generally more prone to energy poverty (Karpinska and Śmiech, 2023). The influence of country-level variables on energy poverty varies depending on the model specifications, leading to inconsistent results.

**Table 3**
Results with additional independent variables that use the fixed-effect linear regression model.

| | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| *Urbanisation:* densely populated area | 0.013*** (0.002) | 0.010*** (0.002) | 0.010*** (0.002) | 0.005* (0.002) |
| *Urbanisation*: intermediate area | 0.011*** (0.001) | 0.010*** (0.001) | 0.010*** (0.001) | 0.003** (0.001) |
| *Dwelling*: semi-detached or terraced house | −0.008*** (0.002) | −0.006** (0.002) | −0.006** (0.002) | −0.007*** (0.002) |
| *Dwelling*: apartment or flat in a building with less than 10 dwellings | −0.020*** (0.002) | −0.018*** (0.001) | −0.018*** (0.001) | −0.013*** (0.002) |
| *Dwelling*: apartment or flat in a building with 10 or more dwellings | −0.028*** (0.001) | −0.025*** (0.001) | −0.025*** (0.001) | −0.027*** (0.002) |
| *Tenure*: Tenant or subtenant paying rent at prevailing or market rate | 0.015*** (0.001) | 0.016*** (0.001) | 0.016*** (0.001) | 0.026*** (0.002) |
| *Tenure*: Accommodation is rented at a reduced rate | 0.028*** (0.003) | 0.026*** (0.003) | 0.027*** (0.003) | 0.033*** (0.003) |
| *Tenure*: accommodation is provided free | 0.027*** (0.001) | 0.024*** (0.001) | 0.023*** (0.001) | 0.019* (0.008) |
| *Room* | −0.003*** (0.001) | −0.003*** (0.001) | −0.003*** (0.001) | 0.001 (0.000) |
| *Leaking* | −0.086*** (0.001) | −0.077*** (0.001) | −0.077*** (0.001) | −0.056*** (0.002) |
| *Mortgage* | – | – | – | 0.071*** (0.003) |
| *Meet* | −0.070*** (0.001) | – | – | – |
| *Meet*: with difficulty | – | −0.174*** (0.004) | −0.176*** (0.004) | −0.129*** (0.003) |
| *Meet*: with some difficulty | – | −0.272*** (0.005) | −0.275*** (0.005) | −0.203*** (0.003) |
| *Meet*: fairly easily | – | −0.306*** (0.005) | −0.309*** (0.005) | −0.221*** (0.003) |
| *Meet*: easily | – | −0.307*** (0.005) | −0.310*** (0.005) | −0.219*** (0.003) |
| *Meet*: very easily | – | −0.298*** (0.004) | −0.300*** (0.004) | −0.213*** (0.003) |
| *Noise* | −0.007*** (0.001) | −0.008*** (0.001) | −0.008*** (0.001) | −0.008*** (0.001) |
| *Pollution* | −0.014*** (0.001) | −0.012*** (0.001) | −0.013*** (0.001) | −0.016*** (0.002) |
| *Crime* | −0.023*** (0.002) | −0.020*** (0.001) | −0.021*** (0.001) | −0.012*** (0.001) |
| *Size* | −0.029*** (0.001) | −0.023*** (0.001) | −0.023*** (0.001) | 0.006* (0.003) |
| *Crowd* | 0.020*** (0.001) | 0.012*** (0.001) | 0.012*** (0.001) | 0.003 (0.002) |
| *Income* (1/1000000) | −0.066*** (0.015) | −0.202*** (0.032) | −0.228*** (0.039) | – |
| *Wealth* (1/1000) | −0.004* (0.002) | −0.004** (0.001) | −0.005* (0.002) | −0.002 (0.001) |
| *Type: One person household* | – | – | – | 0.019*** (0.002) |
| *Type: 2 adults, no dependent children, both adults under 65 years* | – | – | – | 0.003 (0.003) |
| *Type: 2 adults, no dependent children, at least one adult 65 years or more* | – | – | – | 0.012** (0.004) |
| *Type: Other households without dependent children* | – | – | – | 0.005 (0.005) |
| *Type: 2 adults, one dependent child* | – | – | – | −0.013*** (0.003) |
| *Type: 2 adults, two dependent children* | – | – | – | −0.018*** (0.004) |
| *Type: 2 adults, three or more dependent children* | – | – | – | −0.019** (0.006) |
| *Type: Other households with dependent children* | – | – | – | −0.003 (0.006) |
| *Type: Other* | – | – | – | −0.013 (0.007) |
| *Poverty* | – | – | – | 0.046*** (0.001) |

(*continued on next page*)

**Table 3** (*continued*)

| | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| *HDD* (1/1000) | −0.023** | – | −0.023** | 0.001 |
| | (0.007) | | (0.007) | (0.005) |
| *CDD* (1/1000) | 0.055 | – | 0.061 | 0.090 |
| | (0.054) | | (0.054) | (0.064) |
| *ElectricityPrice* | 0.245* | – | 0.227 | 0.056 |
| | (0.097) | | (0.109) | (0.048) |
| *Renewable* | −0.000 | – | −0.001 | 0.001 |
| | (0.001) | | (0.001) | (0.001) |
| *Employment* | −0.001 | – | −0.001 | −0.002* |
| | (0.001) | | (0.001) | (0.001) |
| *GHG* (1/1000) | −0.082 | – | −0.073 | 0.017 |
| | (0.176) | | (0.198) | (0.121) |
| *GDP* (1/1000000) | 0.825 | – | 0.722 | −0.577 |
| | (0.570) | | (0.561) | (0.320) |
| Constant | 0.577*** | 0.506*** | 0.564*** | 0.454*** |
| | (0.077) | (0.006) | (0.079) | (0.050) |
| Observations | 2,227,609 | 2,399,823 | 2,227,609 | 740,763 |
| Adjusted R-squared | 0.192 | 0.214 | 0.216 | 0.249 |

Notes: The reference categories for the variables are as follows: *Urbanisation* is based on "thinly populated area," *Dwelling* on "detached house," *Tenure* on "owner," *Meet* on "with great difficulty," and *Type* on "single parent household, one or more dependent children." Statistical significance levels are indicated by *** for the 0.1 % level, ** for the 1 % level, and * for the 5 % level. All analyses incorporate fixed effects for households and years, with the values in parentheses representing clustered-robust standard errors.

## 6. Discussion

Energy poverty is affected by a myriad of factors, making its assessment notably challenging, particularly at the household level. This study aims to identify the determinants of energy poverty to aid in shaping policies that assist households grappling with these issues. The research presents compelling insights, with some findings aligning with existing literature, while others diverge.

Our empirical results indicate that both substandard housing conditions and the surrounding environment have a substantial impact on energy poverty, underscoring the significance of household energy efficiency. In line with this, Hasheminasab et al. (2023) have highlighted building energy efficiency as a crucial metric for identifying energy poverty. Various scholars have similarly observed that energy poverty often arises from inadequate energy efficiency in buildings and poor housing and environmental conditions (Primc et al., 2019; Ben Cheikh et al., 2023).

This underscores the necessity of government initiatives to enhance building energy efficiency through financial programmes. Improving energy efficiency enables households to redirect funds typically lost to energy inefficiencies towards covering energy costs. Mulder et al. (2023) advocate for a holistic approach to addressing energy poverty, which includes increased financial support, price incentives, and home insulation standards. Enhancing energy performance in housing not only promotes more efficient resource use and economic recovery but also supports the EU's energy and climate goals. It is crucial to ensure that the most vulnerable households benefit from energy efficiency investments by identifying and overcoming barriers to accessing these resources. EU energy policies should prioritise public education on the advantages of modern appliances and smart technologies for optimising energy efficiency and achieving long-term savings. Many individuals at risk of energy poverty lack awareness of these technologies, highlighting the need for increased education on effective strategies to enhance household energy efficiency. Additionally, our findings suggest that households situated in adverse environments marked by noise, pollution, and crime are more likely to experience energy poverty.

The results clearly demonstrate that socioeconomic factors, especially income, are crucial for understanding the scope of multidimensional energy poverty among EU households. Those facing financial difficulties are at a heightened risk of encountering this issue, a conclusion supported by numerous studies (Bollino and Botti, 2017; Betto et al., 2020; Deller et al., 2021; Awan et al., 2022; Karpinska and Śmiech, 2023). On the other hand, Galvin (2019) highlights that financial constraints experienced by lower-income households often prevent them from covering the costs of electricity and heating. Moreover, households with significant income disparities and limited assets are more susceptible to energy poverty. This suggests that economic downturns exacerbate energy poverty conditions, and future economic crises are likely to have similar effects. Hence, it is crucial to implement preventative measures against economic crises, such as investing in renewable energy sources and fostering competition among energy suppliers to enhance economic stability and resilience. Additionally, policies aimed at improving income distribution can play a vital role in enhancing access to energy services and alleviating poverty.

Another key finding of our study is the prevalence of energy poverty in overcrowded households. This observation aligns with the findings of Karpinska and Śmiech (2020a, 2020b) and Ben Cheikh et al. (2023), who emphasised the need for substantial support for families with multiple dependents. Policies designed to assist households with dependent children could not only alleviate energy poverty but also positively influence demographic trends. Research has consistently identified a significant correlation between household size or family size and energy poverty (Dogan et al., 2021). Karpinska and Śmiech (2023) noted that the likelihood of experiencing energy poverty is greater among households with dependent children and larger family sizes. Conversely, studies by Legendre and Ricci (2015) and Jack and Ivanova (2021) found that individuals living alone or in smaller households also face increased risks of energy poverty.

The study revealed a positive association between housing tenure and energy poverty, with renters exhibiting a higher propensity for energy poverty compared to homeowners. This finding corroborates Abbas et al. (2020), who documented an elevated risk of energy poverty among renters relative to homeowners. Belaïd (2018) observed that renters are often more vulnerable due to their limited ability to implement energy-efficient upgrades to their properties. This vulnerability can be exacerbated by rising rental costs and rigid housing markets, which further strain renters' financial capacity (Karpinska and Śmiech, 2023). Additionally, Papantonis et al. (2022) highlighted significant challenges faced by private renters regarding home energy efficiency, thereby increasing their susceptibility to energy poverty. Ben Cheikh et al. (2023) also supported our findings, noting that tenure status, alongside factors such as urbanisation and overcrowding, can intensify issues related to energy poverty. Addressing the role of the rental market in combating energy poverty, it is crucial to develop policies that enhance the availability of affordable housing options for low and middle-income households. Governments should consider fostering public-private partnerships to build affordable housing and support energy-poor households in acquiring homes through manageable financing options.

Our analysis further indicated that detached houses typically incur higher energy consumption for heating, cooling, and maintenance compared to other housing types, due to their lack of shared walls and communal areas. This observation is consistent with Karpinska and Śmiech (2023). Moreover, households with a greater number of rooms per person generally experience fewer issues related to leaks, dampness, or decay, largely attributed to their higher wealth levels, which mitigates their risk of energy poverty. However, Halkos and Gkampoura (2021) noted ongoing debate regarding the relationship between insufficient home heating and the ratio of rooms to occupants. In contrast, our results demonstrated a positive correlation between urban population density and the difficulty of maintaining homes at adequate warmth levels. This suggests that urbanisation exacerbates energy poverty, aligning with Rodriguez-Alvarez et al. (2021). This finding contrasts with other studies that suggest urbanisation may reduce energy poverty (Bollino and Botti, 2017; Halkos and Gkampoura, 2021; Ben Cheikh et al., 2023). Effective strategies to mitigate urban energy poverty include offering financial aid or subsidies for energy bills to low-income households, promoting renewable energy through subsidised solar panel programs, and expanding energy infrastructure in urban areas. Additionally, initiatives encouraging migration from urban to rural areas could also contribute to addressing this issue.

Our results also indicate that smaller households with fewer rooms are more likely to experience elevated levels of energy poverty. This finding aligns with Abbas et al. (2020) and Ben Cheikh et al. (2023), who observed that larger homes, typically owned by wealthier households, are less prone to energy poverty. Conversely, Karpinska and Śmiech (2023) reported that larger households may face increased energy poverty due to their higher energy needs for heating and cooling.

The adoption of renewable energy sources is widely recognised as a strategy to combat climate change and reduce associated costs. Consequently, European countries are actively engaging in an energy transition towards renewables. Nevertheless, our study reveals that, at present, renewable energy does not significantly alleviate energy poverty across Europe. This observation aligns with the findings of Ben Cheikh et al. (2023), who reported a weak and negative correlation between renewable energy use and energy poverty rates. However, fostering domestic renewable energy adoption through targeted policies could still be beneficial, as it may reduce dependence on imported energy and subsequently lower energy costs.

Additionally, the cost of electricity for household consumers emerges as a critical factor influencing energy poverty. Previous research has examined electricity and gas prices as key determinants of energy poverty (Tundys et al., 2021; Rodriguez-Alvarez et al., 2021; Kryk and Guzowska, 2023). Consistent with Betto et al. (2020), Halkos and Gkampoura (2021), and Ben Cheikh et al. (2023), our findings indicate that higher electricity prices can exacerbate energy poverty issues. To address this, policies aimed at reducing electricity costs for consumers are essential. Governments should consider regulatory reforms to cap energy prices, advocate for market liberalisation, or enforce equitable pricing practices within the energy sector. Additionally, targeted financial assistance, such as cash aid, discounted energy programmes, or energy vouchers, can help alleviate the burden on low-income households. Providing tax incentives for investments in renewable energy and energy-efficient appliances can also contribute to lowering overall household energy expenditures.

Ultimately, the research findings provide valuable insights for governments and policymakers by highlighting the complex nature of energy poverty, particularly in the context of financial and energy crises across Europe. The insights gained are crucial for identifying key factors contributing to energy poverty. Effective strategies could include reducing energy costs, increasing household incomes, and enhancing energy efficiency to mitigate energy poverty. By adopting a policy framework informed by these findings and recommendations, it is possible not only to reduce energy poverty but also to promote long-term sustainability, energy independence, and resilience. This proactive approach will help address potential future economic downturns and mitigate the impact of unforeseen events, such as the COVID-19 pandemic and the Ukraine-Russia conflict, which have directly affected energy poverty levels.

## 7. Conclusions

Energy poverty, characterised by its intricate and multifaceted nature, has emerged as a critical concern for both global stakeholders and the European Union. In recent years, the situation has worsened, necessitating that European policymakers explore innovative approaches and expand evidence-based solutions to support and protect vulnerable households. Our study conducted a comprehensive analysis of energy poverty at the household level across 32 economies, including both EU and non-EU countries, from 2004 to 2021. This analysis integrated household characteristics with country-level data within a cross-country framework. We specifically examined socioeconomic, institutional, and environmental factors that may influence energy poverty either directly or indirectly. By gaining a nuanced understanding of these drivers, policymakers can develop more precise and effective policy recommendations.

The research results revealed a positive correlation between energy poverty and the variables of Urbanisation, Tenure, Crowd, Electricity price, and GDP. Conversely, the remaining variables—Dwelling, Room, Leaking, Meet, Noise, Pollution, Crime, Size, Income, Wealth, Renewable, Employment, and GHG—displayed negative coefficients. These observations led us to conclude that households residing in unfavorable housing conditions and surrounding environment, as well as those facing financial challenges, are more likely to experience energy poverty.

While the adoption of renewable energy is crucial for addressing climate change and achieving a successful energy transition, our findings indicate that it does not currently mitigate energy poverty in Europe. Instead, tackling energy poverty requires addressing rising energy costs, inadequate housing conditions, and income inequality. Given the diversity in socioeconomic factors, climatic conditions, and energy market structures across the EU, it is advisable to implement customised government incentives and support programmes aimed at improving energy efficiency in low-income households. Investing in building energy efficiency is vital, as it enhances housing conditions, reduces energy consumption, and mitigates energy losses. Promoting sustainable housing options should also be encouraged.

Addressing challenges such as low energy literacy and financial constraints, which impede the most vulnerable individuals from accessing interventions and recovery strategies to improve building efficiency, is essential. To assist those affected by energy poverty, it is important to provide financial support for building renovations, offer subsidies for technologies like heat pumps and solar panels, and implement structural measures to enhance energy efficiency. Initiatives that boost disposable income, such as generating employment opportunities and supporting the growth of low-skilled service sectors, can further help reduce energy poverty. This includes aiding individuals transitioning from the fossil fuel industry to cleaner energy alternatives.

Additionally, increased support should be directed towards large families with dependent children. Investing in rural community development may encourage residents to stay in these areas, thereby reducing urban migration and its impact on energy poverty. Moreover, establishing a uniform definition of energy poverty across the EU and implementing a standardised set of indicators for monitoring should be key priorities.

Although the EU has implemented numerous policies to address energy poverty, there remains a significant need for continued enhancement of these efforts. To further this work, additional research is required. For a more comprehensive understanding of energy poverty at the household level, particularly in regions with varied climates or significant urban-rural contrasts, a more in-depth spatial analysis is advisable. Future research could integrate additional factors, such as subjective experiences and educational attainment, and examine how energy poverty is in alignment with SDGs. Future studies could also develop methods for evaluating sustainable energy poverty by establishing criteria and choosing appropriate assessment techniques. Another important future development should include considering data on energy efficiency renovations, which will become available in the EU-SILC database starting in 2025. Furthermore, recognising the diverse demographic profiles within households and identifying different forms of energy poverty can improve the evaluation of policy effectiveness. Additionally, future research should focus on regularly updating analyses and exploring energy poverty in both developed and developing countries, including comparative studies between these areas.

**CRediT authorship contribution statement**

**Georgia Makridou:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project

administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Ken'ichi Matsumoto:** Writing – original draft, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Michalis Doumpos:** Investigation.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2024.108020.

## Data availability

The data utilised for this research is confidential.

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