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Boosting green energy transition to tackle energy poverty in Europe

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ABSTRACT

Global COVID-19 pandemic exacerbated household energy poverty in many countries. During the latter half of 2021, as the situation gradually improved, a new threat emerged in the form of energy prices' inflationary surge, exacerbated by the Russian-Ukrainian conflict. This paper attempts to provide pragmatic projections of energy poverty in European countries over the next five years. Furthermore, the study will investigate whether nations that actively support the transition to green energy will be advantaged to mitigate the consequent adverse effects on the energy poverty situation. Findings indicate that several factors contribute to energy poverty in European countries, and the short-term outlook does not look good. As a result of the inflationary rise in energy prices and the lingering economic effects of the pandemic as well as geopolitical tensions, households face significant obstacles to achieving energy security and affordability. A glimmer of hope exists, however, for countries that prioritize and boost green energy transitions. Despite recent adversity, these nations may have an advantage in recovering more quickly. A shift to renewable energy sources may contribute to a more resilient and stable energy landscape by protecting countries from the volatile nature of traditional energy markets and geopolitical conflicts. Green energy infrastructure is essential for addressing the immediate and long-term challenges of energy poverty. The government and policymakers are urged to consider sustainable energy transition not only as a means of combating climate change, but also as an essential component of economic recovery and social well-being, particularly in the context of unpredictable global events.

1. Introduction

Since the '70s oil crisis, energy poverty has become one of the most critical factors in determining economic and social household deprivation [1–3]. Energy poverty (hereafter, EP) is a recognized a kind of material deprivation affecting the quality of life [4], including mental health, social inclusion, environmental quality, and productivity. The concept of EP can be declined in many manners according to the examined context, its environmental conditions, and socioeconomic features, affecting the selection and operability of different policy solutions [5]. It is affected by multiple factors, such as income inequality, housing energy efficiency, and energy prices (e.g., [6]). Nevertheless, understanding EP is essential for introducing effective policy measures [7].

As many practical consequences may result from adopting different definitions, scholars recommend [8,9] to refrain from broad based definitions and to focus on specific aspects of the investigations. Moreover, many scholars use EP interchangeably with fuel poverty (FP), commonly employed when households suffer from insufficient monetary resources to pay for their basic energy needs. As argued by Li et al. [10], EP and FP are descriptors of household energy consumption problems; although they are different concepts, they have been cross-used by researchers, organizations, and governments alike. Cross-use of the terms energy poverty and fuel poverty in published papers is common.

With this in mind, we refer to the Citizen Energy Forum definition, which represents the EP as "a situation in which a family or individual is unable to pay for primary energy services (heating, cooling, lighting, movement, and electricity) necessary to guarantee a decent standard of living, due to a combination of low income, high energy expenditure, and low energy efficiency in one's own homes." This statement assumes, de facto, the definition of fuel poverty.[1]

Over the years, EP has become central in EU economic policies and aimed at reducing the inequalities among the population. The European Commission estimates that, in 2022, about 9.3 % (8 % in 2020) of the EU population, equivalent to 41 million people, could not keep their homes adequately warm [11]. However, this data is affected by high

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[1] In the remainder of the paper we will use the concept of energy or fuel poverty crosswise, while referring to the concept of fuel poverty.

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heteroscedasticity since significant differences among countries are shown. Actually, countries with the largest share of the population were unable to keep their homes adequately warm in 2020 are Bulgaria (27 %), followed by Lithuania (23 %), Cyprus (21 %), Portugal and Greece (17 %).

The increasing incidence of EP in European households is due to the effects of the COVID-19 crisis (e.g., [12]). In addition to the pandemic health crisis, the war between Russia and Ukraine has led to higher prices for energy products, exacerbating EP. The purchasing power of households, especially those most vulnerable, has been eroded by the inflation spiral triggered by the coincidence of the end of the acute pandemic phase and the beginning of the war between Russia and Ukraine. Recently, Carfora et al. [13] showed that the pandemic increased the share of households with heating difficulties and that the first positive effects of returning to pre-pandemic levels will not be seen until 2024. However, the proposed forecasting framework did not consider the rise in energy prices, which has impacted European households significantly. This impact is partly due to the heavy energy dependence of EU countries on foreign sources. The rise in energy prices has increased energy bills and strained many households' budgets. When developing forecasting frameworks, it is essential to include the impact of energy prices to reflect the households' economic and financial conditions accurately.

The European Commission (EC) decided to accelerate the transition from a predominantly fossil-based energy generation system to one more reliant on renewable sources to reduce dependence. It raised the planned targets and recently set them at 45 % by 2030 [14]. In addition, agreements have been signed with third countries, especially in North Africa, to increase imports to make up for the decreasing flow from Russia. As highlighted by some previous studies [15–17], energy transition can be a driver to mitigate energy poverty.

The empirical models exploring the determinants of EP can be used to support policymakers in their work to assess the impact of different policy options [18]. For this reason, this paper aims to provide a valuable tool to support challenging policy decisions and identify how to reach the medium-term goals to alleviate EP. With this in mind, the paper addresses two research questions. Firstly, it aims to investigate whether countries supporting a path toward a fully green energy transition better manage price fluctuations and the adverse effects of ongoing social, political, and economic crises on energy poverty. Secondly, by providing energy poverty predictions for European countries over the next five years, it aims to investigate whether, and when European countries will be able to emerge from the deepening energy poverty that occurred as a consequence of the pandemic effects and rapid rise in energy prices. Since the main challenge in making these forecasts is the lack of data beyond 2020, the paper proposes estimating a model based on dynamic factors to enable a forward projection of the determinants of EP. This study assumes three scenarios to account for uncertainty in the trend of the energy transition. The first scenario is conservative or pessimistic, simulating a stagnation period in the first five years of the energy transition. The second scenario is intermediate, simulating linear growth toward full transition. Finally, the third scenario is more optimistic and assumes exponential growth toward a complete energy transition. As a result of the work carried out to address these two research questions, the paper makes three main contributions to the existing literature dealing with EP. It shows that (i) the faster the energy transition, the greater the action to tackle EP can be; (ii) encouraging the adoption of renewable energy can help reduce long-term energy costs and improve household energy resilience; (iii) countries less affected by EP are also the ones in which there is greater diffusion of energy generated from renewable sources. The remain of the paper is organized as follows: Section 2 presents the framework of the research. Section 3 illustrates the empirical strategy adopted, while findings and robustness checks are reported in Section 4. Section 5 is devoted to the scenarios analysis, while Section 6 concludes.

2. The background underlying the theoretical design

This section introduces the contextual framework and proposes a theoretical design that will lead to the investigation of the EP in European countries that are actually managing price fluctuations and the effects of ongoing social, political, and economic crises.

More specifically, once the framework is well defined, a theoretical design will be followed to assess whether supporting a transition to green energy might be useful for countries to mitigate the negative consequences caused by the harsh conditions they are facing.

2.1. Contextual framework

The health crisis due to the recent pandemic wave and the international tensions between Russia and Ukraine has significantly impacted the world economic system, mainly Europe.

The need to contain the spread of the virus among the population has severely led political authorities to restrict travel and activities. This caused the closure of economic activities, the reduction of the employment rate, and, consequently, the reduction of gross domestic product. In the context of the European Union, there was a sharp contraction in GDP in 2020, averaging 5.6 %, involving almost all member countries. Spain and Greece and Italy led the way, with declines of 11.3 %, 9 % and 9 % respectively.[2] In the wake of the spread of the pandemic, European institutions have developed joint proposals to deal with the massive health, economic, and social consequences and to provide the financial support needed to mitigate the effects on populations and productive activities of the contagion containment measures launched by national governments.

The Europe-wide coordinated vaccination campaign helped limit the effects of the pandemic and widen the mesh of restrictions with a gradual return to normalcy. This countered the negative impact on the economic system and on the employment, leading to the economic recovery that made it possible to recover as early as 2021 the losses in GDP recorded the previous year. Once the worst health crisis had passed, another storm hit Europe with the start of the war between Russia and Ukraine and the ensuing sanctions that reduced imports of energy commodities, mainly natural gas, from Russia. European countries had an import dependency rate of 83.6 % in 2020 (importing 400.6 billion cubic meters). They have significantly increased their reliance on Russian natural gas, which has grown over the last decade, reaching, in 2020, 41.1 % of gross available energy (Fig. 1). Fig. 1 shows the import dependency rate of natural gas from Russia in 2020: it clearly shows how eastern countries are highly dependent on Russian imports, as are two of the largest European economies, Germany and Italy.

In more detail, Fig. 2 shows the composition of natural gas imports into Europe, diversifying the countries of origin. In particular, there is a distinction between the share of imports from Russia and the share of imports from other non-European countries. An analysis of the time trend of the import share shows that the share of gas from Russia is declining rapidly, partly as a result of the diversification policy of some European countries (e.g., Italy) and partly as a result of the supply blocks put in place by Russia through its subsidiary Gazprom.

The combined effect of the end of the pandemic and the international tensions intensified the already near-record rise in consumer prices due to the COVID-19 pandemic and the disruption of supply chains [19]. Consequently, the recent energy crisis led to a decline in imports and a consequent price rise. Focusing on the price of gas for households, as observed in Fig. 3, it remains a range between 0.04 €/KWh and 0.05 €/KWh from 2007 to 2021 (excluding taxes and levies), while it quickly rises above 0.6 €/KWh, starting from 2021-S2.

The rise in gas prices continued in the second half of 2022, caused by

[2] Source: Eurostat, real GDP rate of change (% of change compared with previous year).

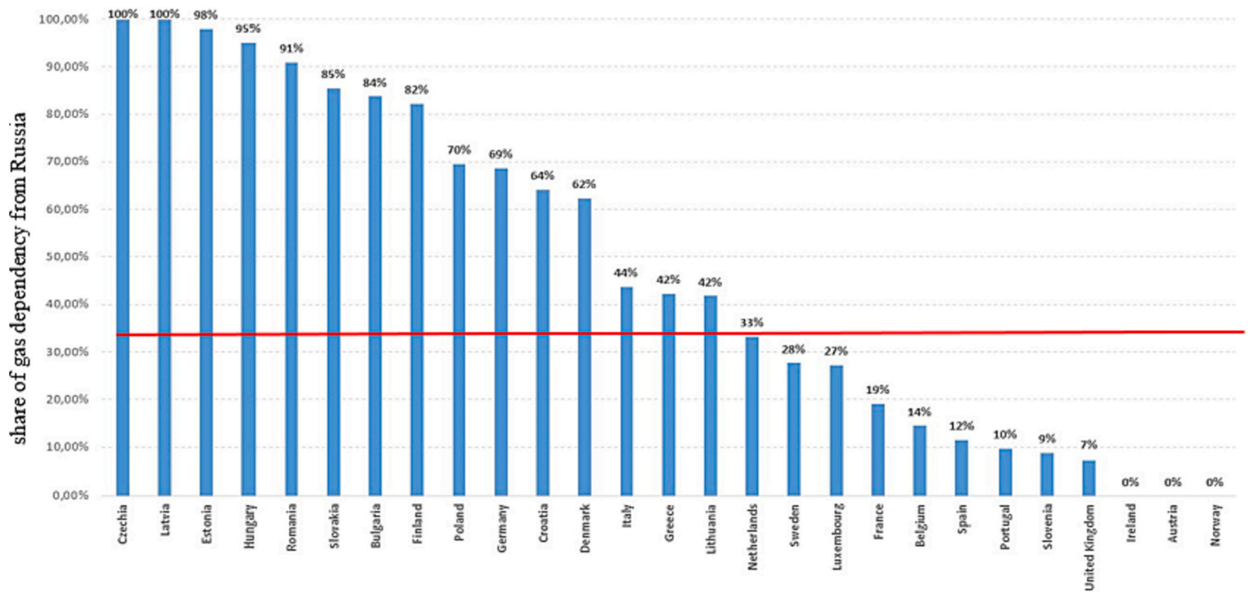

Fig. 1. Natural gas import dependency from Russia.

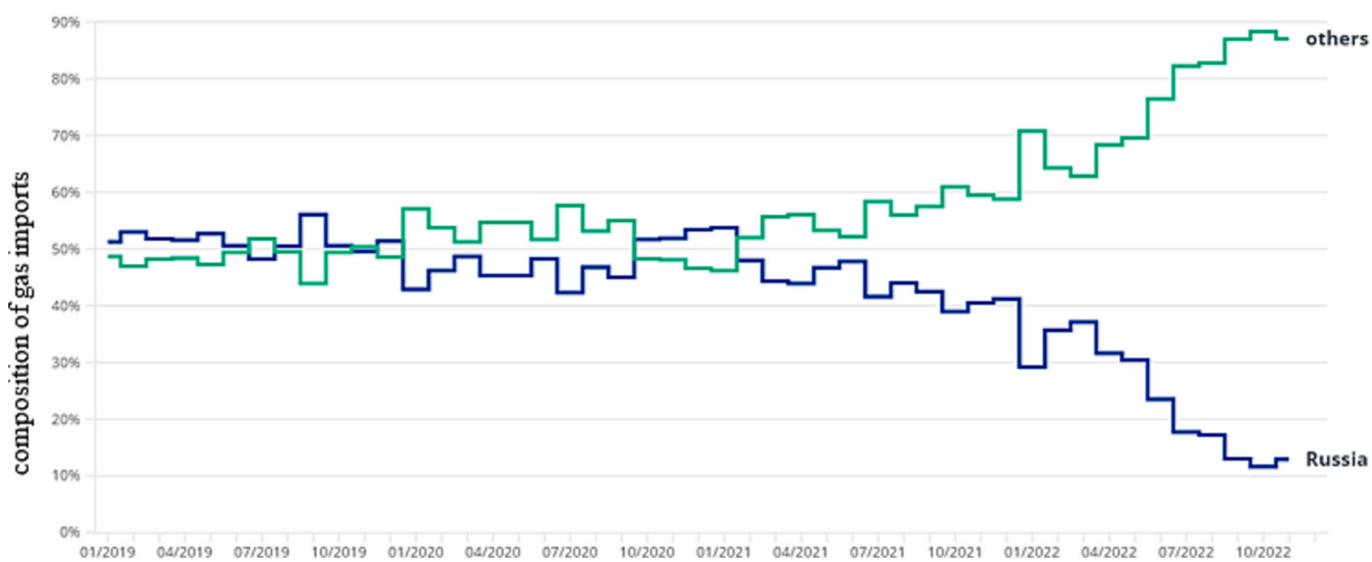

Fig. 2. The EU's diversification away from Russian gas.

the crisis between Russia and Ukraine and the supply reduction. The various supply blocks were reprisal to sanctions passed by European governments. On the other side, the European countries' response to the energy crisis was strong but inflated, also connected with the actions of profiteers, fearing insufficient supplies for the winter season.

As Kammer [19] recently pointed out in the IMF's blog, European countries have increased storage quotas before the winter season, although any disruption to incoming flows could jeopardize its resilience. This would impact the economic system, estimated at around 3 % of GDP, and could trigger further inflation. As an additional restraint on the rising pressure and to curb speculative attacks, the EC introduced a cap on the gas price, set at 180€/MWh.

Price growth has implications, especially for vulnerable households, and rising energy prices promote the widespread of energy-stressed families, exacerbating poverty. In a nutshell, economic policies should make it possible to reduce inflation while helping vulnerable households (and firms) cope with the energy crisis.

The recent energy crisis has exposed all the weaknesses in Europe's electricity supply and generation system. As has been pointed out, high energy dependence makes countries particularly vulnerable to external crises. For this reason, the European Commission has expressed its firm will accelerate the transition to renewable sources, revising the targets already planned for 2030 and raising them from 30 % to 45 % [14].

The transition to clean sources will make it possible to reduce the EU's dependence on third countries. As Lippert and Sareen [20] suggest, there is a need to promote the transition further while adapting the energy infrastructure. Still, it should also have a calming effect on energy prices, no longer dependent on quotations. After all, as Hashemi-nasab et al. [21] recently pointed out, accelerating the energy transition makes tackling EP in European countries possible.

Fig. 4 summarizes the distribution of European countries according to the average over the past ten years of the difference between the share of generation from fossil and renewable sources (outlining the transition) and an energy poverty indicator: the percentage of the population reporting that they cannot keep their homes adequately warm (source: EU Survey on Income and Living Conditions).

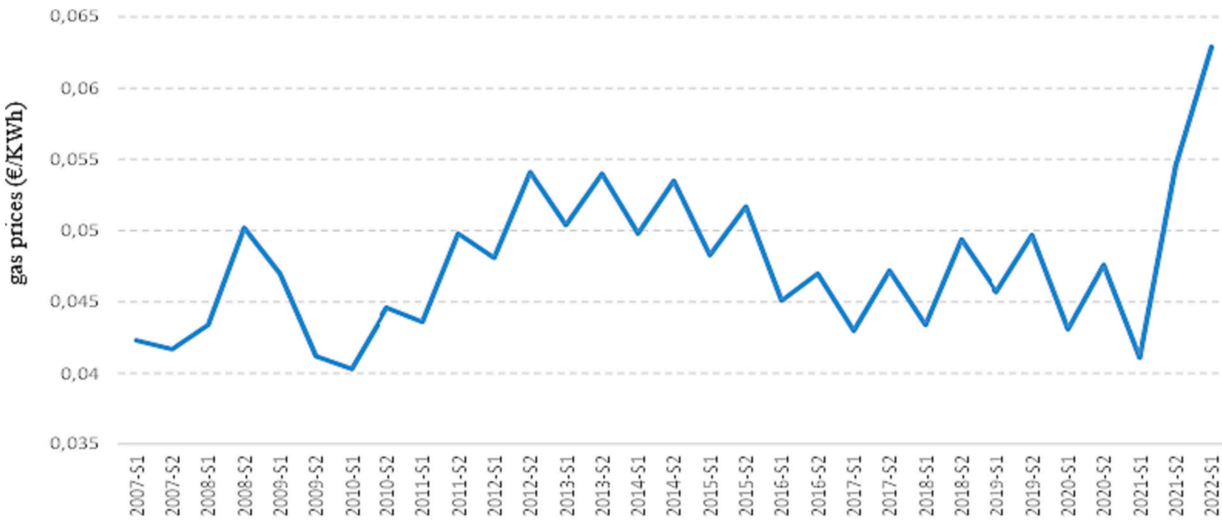

Fig. 3. EU 27 countries (from 2020) average gas prices for household consumers - bi-annual data.

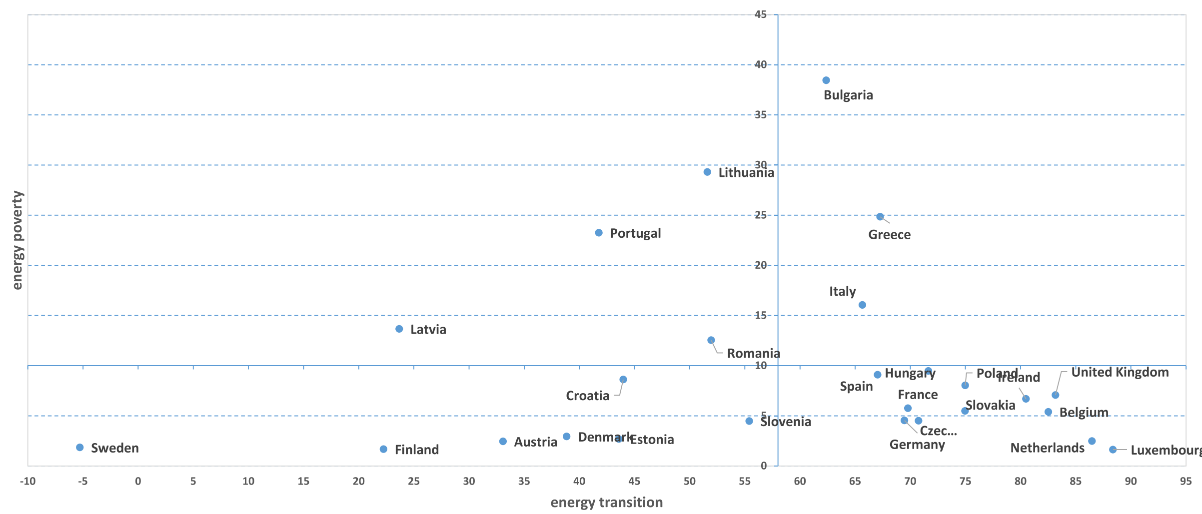

Fig. 4. Energy transition vs. energy poverty.

It shows that countries below the EP average (x-axis) are those where EP involves fewer households. They have a large share of generation from renewable sources (most exceed the average level represented by the vertical axes) or varied generation baskets, including nuclear power that contributes to an ample supply of base-load electricity and keeps prices low. High per capita wealth levels also mark some of these in each case. Conversely, some countries have a share of EP higher than the average value. Some countries have a similar transition level to those below the EP average. However, it should be noted that they have a lower level of wealth or, in any case, a limited generation basket (which does not include nuclear power).

Recent studies on single countries have shown that demographic and socioeconomic factors like the energy sources of climate and transport [15] and the risk of deepening socioeconomic inequalities [16] affect EP. Bartazzi et al. [22] studied the relationship between economic inequality and energy poverty within Italian regions, finding a correlation between income inequality and energy poverty indicators. They stress the importance of adopting comprehensive strategies to address energy poverty, which should be implemented considering each region's specific territorial characteristics.

Priesmann et al. [23] investigate the impacts of renewable energy support levies on income inequality and energy poverty. They highlight how energy transition involves substantial costs, which, in many cases, are passed proportionally on to final energy consumers as levies on electricity consumption, and suggest reforming the levies system to reduce income inequality and energy poverty. Stojilovska et al. [24], drawing from the lived experiences of energy-vulnerable households in five diverse European countries: Portugal, Slovakia, Hungary, Austria, and North Macedonia, shed light on the significant role of fuelwood in the lives of energy-vulnerable households and the cultural practices that have evolved around its use as a means of coping with energy poverty.

Mulder et al. [25] addressed the topic in the Netherlands through spatial analysis, arguing that EP is much more spatially concentrated than income poverty and is caused by an investment barrier.. Focusing on the Czech Republic, David and Koďousková [26] examine the real-life experiences of households and connect these experiences with the official narratives surrounding energy poverty. They advocate for a collaborative effort between the government and non-government sectors to reduce the increasing risk of households to fall in the cycle of energy poverty.

In a recent paper, Pereira and Marques [17] highlight that energy forms have differing impacts on EP in areas with different levels of urbanisation. Using data from 2005 until 2018 for twelve European countries, the authors indicated that EP could be alleviated in rural areas using primary energy sources, such as wood/biomass and natural gas. Karpinska and Smiech [27], analyzing 11 countries of Central and

Eastern Europe, identify distinct profiles of energy-poor households, each associated with specific vulnerability characteristics (e.g., low income, type of housing, mismatch between the size of their housing and their household needs), suggesting to adjust the housing market and improve the living conditions of vulnerable citizens.

Shifting the focus to some emerging economies (Brazil, China, India, Indonesia, Mexico, and Russia), a recent study by Khan et al. [28] analyzes the long-run cointegrating relationship between EP and its determinants. Varo et al. [29] set up a panel of experts composed of scholars and practitioners specialized in EP from 38 countries to capture the diversity of measures to tackle EP. Their findings gave a better perspective on innovation's shape in the context of EP policies. However, one of the limitations of the works cited concerns that although they are very recent, they analyze the phenomenon before the Covid 19 pandemic. The consequences of the coronavirus pandemic could affect a greater number of vulnerable people, thus increasing energy poverty [30]. The pandemic represented a turning point by making EP a challenge for all countries. It occurred because with people being forced to stay at home, the comfort of houses and their willingness made the inequalities even more evident. In the literature, among the papers considering the pandemic effect as one of the factors favoring EP, it is proper to include the recent article by Liu and Feng [31]. They examine the short- and long-term effects of energy legislation promoting renewable energy generation, distinguishing between high- and upper-middle-income and lower-middle and low-income countries, using panel data on energy-related climate change legislation in 129 countries between 2001 and 2020. Focusing on the European countries, Panarello and Gatto [32], in a recent paper investigating the EU citizens' perception of renewable energy transition, grasp a stronger relationship regarding institutional responsibility to address EP.

Moreover, their results indicated that if the institutional intention is addressing EP, the development of renewable energy should be considered by policymakers. Similarly, Hasheminasab et al. [21] assess the 27 EU countries between 2015 and 2020, concluding that renewable energy sources can satisfy the energy demand and tackle EP. Considering these three pillars, energy would be accessible, affordable, and sustained among various generations.

2.2. Theoretical framework

The theoretical framework leading to the contextual factors outlined so far is based on the Rodriguez-Alvarez et al. [33] design empirically applied to a sample of 30 European countries. Since the policymakers' goal is to improve the quality conditions of citizens' lives, their theoretical framework employs a utility function measuring the well-being that the people of each country achieve when EP is reduced. The authors define the utility level of EP that a country can achieve, given its income level and energy prices, as:

$$U = U(Y, P)$$

where U is the indirect utility function that represents the individual's utility or well-being with a bundle of goods when faced with a vector of energy prices (P) and an amount of income (Y). U fulfils the following properties:

$$\frac{dU(Y,P)}{d(Y)} > 0; \frac{dU(Y,P)}{d(P)} < 0$$

Under these assumptions, U will have a positive relationship with Y and a negative relationship with P.

Among other purposes, policymakers aim to reduce the EP level as much as possible, given their income level and prices. Based on this theoretical design, let $\overline{U}^z$ as the utility level obtained from a bundle of goods that allows individuals in a country to live above the EP line (z) and U^o as the observed utility of the basket of goods that individuals have. When households experience EP situation, the policymakers will be concerned with implementing all the measures to ensure U^o at least equal to $\overline{U}^z$, adopting the policies needed to close the gap between the two utility levels:

$$U^o = \overline{U}^z + v \tag{1}$$

In Eq. (1), v is a measure of the efficiency to achieve the utility level leading to a condition allowing all the individuals to live above the EP line. It summarizes all the efforts with which each country can tackle EP, and include the energy transition (ET) and other endogenous factors ($\mathbf{X}$) such as $v = f(\mathrm{ET}, \mathbf{X})$ so that

$$U^0 = f(\mathrm{Y}, \mathrm{P}) + f(\mathrm{ET}, \mathbf{X}) \tag{2}$$

The theoretical scheme meets the European Parliament claims recently revealed by a briefing on energy poverty in EU member countries [11]. In this report, it is clearly argued that EU Member States with higher per capita GDP levels exhibit the most favorable outcomes in addressing energy poverty, as well as that rising electricity prices have increased the share of vulnerable households. The final briefing's report highlights that Sweden has the lowest energy poverty score, whereas Slovakia, Hungary, and Bulgaria recorded the highest. The report underlines the noticeable divergences in EP scores. In particular, it emphasizes the divergences between the lower levels in Western and Northern European countries compared to the higher levels in Eastern and South-Eastern European and Baltic countries.

The European Green Deal toward an energy system in line with the EU's climate neutrality goals needs to address EP to ensure this transition will be fair. This involves planning measures aimed at households unable to meet their essential energy needs and the consequences of the recent rapid energy price increase [11]. Therefore, it is prudent to consider whether the ongoing energy transformation will help in improving accessibility and whether the technology currently in use can effectively reduce the associated utility costs [34]. Furthermore, it is relevant to consider whether the widespread adoption of affordable and efficient renewable energy sources would have the power to alleviate the problem of energy poverty affecting households in European economies [35].

Given the previous points, it would be desirable for the ambit of energy transition to include not only the ensuring of energy supply assurance but also efforts to mitigate EP [36,37]. As underscored by the United Nations in 2021 [38], “It has been long recognized that the global energy system needs to change. But if there ever was any doubt, the COVID-19 pandemic has cemented that resolve. The Covid crisis has demonstrated the weaknesses of the existing energy system and exposed the consequences of energy poverty experienced by billions of people worldwide. Achieving Sustainable Development Goal 7 (SDG7) can fundamentally change this reality.”

In the following sections, the method used to summarize the covariates deemed most appropriate into uncorrelated dynamic factors will be presented; then, these factors will be joined by electricity prices and GDP per capita, and an energy transition indicator will also be considered to assess the two research questions of the paper.

3. Empirical strategy

3.1. Method

The analysis of a complex issue requires the use of quantitative methods, taking into account the complex relationships among the variables. Dynamic factor analysis (DFA) is a statistical dimension-reduction technique for time-series data that meets this need. With this method, starting from a large number of k variables, it can get an outcome of a relatively small number of m common dynamic factors. The number of estimated dynamic factors is equal to the original number of variables, but they are uncorrelated. Moreover, a few factors explain most of the overall variability. The idea underlying the DFA is that a set of time series (y) is modeled as a linear combination of unobserved dynamic factors (x) and dynamic factor loadings (Z), plus some offsets (d). As an autoregressive process drives the dynamic factors, a DFA model has the following structure:

$$\boldsymbol{x}_t = \boldsymbol{x}_{t-1} + \boldsymbol{w}_t$$

$$\boldsymbol{y}_t = \boldsymbol{Z}\boldsymbol{x}_{t-1} + \boldsymbol{d} + \boldsymbol{v}_t$$

where w_t and v_t are uncorrelated and distributed as a multivariate Gaussian process with zero vector mean; w_t with an identity-covariance matrix ($\mathbf{I_m}$). The empirical design, which will be followed in the continuation of the work, involves using the dynamic factors as regressors in several panel model specifications to explain the determinants EP and use them for forecasting purposes. In more detail, after collecting an appropriate number of variables and grouping them into k homogeneous areas, through the DFA one ($m = 1$) latent country extracted by each group, the one accounting for most of the variability, will be used as an explicative variable in the model.

For a generic i-country, each y-time series of the generic k-areas can be expressed by the correspondent dynamic factor so that:

$$\begin{bmatrix} y_{it}^1 = & Zx_{it-1}^1 + & d + v_{it}^1 \\ \vdots & \vdots & \vdots \\ y_{it}^k = & Zx_{it-1}^k + & d + v_{it}^k \end{bmatrix}$$

The model dynamic factors (x_1, x_2, …, x_k) are estimated through a Maximum-Likelihood.

3.2. DFA variables selection

The variables collected to estimate the dynamic factors indicators come from the Eurostat Database. They have been selected considering the Energy Poverty Advisory Hub (EPAH) national-level indicators of EP. EPAH provides periodic indicators update by using the most recent EU-wide statistics. To employ the DFA analysis, 15 time series have been selected to create a balanced panel dataset of 26 countries during the 2007–2020 time span. Among these countries, 25 are EU member states (almost all, only Malta and Cyprus were excluded due to the lack of much of the data collected); meanwhile, the other is the United Kingdom.

The variables were then grouped into three ($k = 3$) homogeneous thematic areas: i) economic and social conditions, ii) environmental degradation, and iii) housing conditions.

Economic and social conditions capture the influence of economic deprivation, inequalities and population pressure. The variables that are covered by this topic area are often used as predictors of the percentage unable to heat their homes, showing a robust correlation [39]. A direct relationship between the coefficient of this area and EP is expected since the individual indicators that compose this area directly influence economic poverty. Housing conditions capture the role of deprivation and inadequate dwellings. We compute this indicator using the data from the EU-SILC dataset. There is a direct correlation between the houses' vulnerability and the energy poverty of households who live there [40]. The worse the housing conditions, the greater the perception of EP by those who live there; therefore, a positive coefficient is also expected.

Energy poverty can accelerate the growth of greenhouse gas emissions [41], which are the main contributors to air pollution. A number of variables related to greenhouse gas levels are considered to represent environmental degradation. In particular, we know that agriculture is a significant source of anthropogenic greenhouse gas emissions and that beef cattle are particularly intensive in terms of emissions (especially methane) [42,43]. Therefore, we introduce cattle population among the variables in this specific topic area. We expect an indirect coefficient, as EP significantly intensifies the rate of carbon emissions.

Their descriptions, the units of measurement, and some descriptive statistics for overall countries are reported in Tables 1 and 2. Detailed descriptive statistics for each country are reported in Appendix (A1 to A4).

3.3. The outcome variable and the model specification

The 2020 European Commission recommendation defines EP as a situation in which households cannot access essential energy services [44]. EP is inherently difficult to measure, and the literature has proposed different approaches to approximate it. They are usually divided (e.g., [33]) into three types: i) Direct, or objective, measurement based on comparing energy service levels achieved and a known benchmark (e.g., [5,45]). As Best et al. [46] argued, the main weakness associated with the objective approach lies in using actual rather than required energy expenditures; ii) Indirect measurement based on indicators such as income, housing costs, or energy costs [47,48]; iii) Consensual or subjective measurement based on self-reported assessments of indoor living conditions, such as whether individuals are able to keep their homes at an adequate temperature (e.g., [49]).

Although objective measures may seemingly show greater reliability when juxtaposed with subjective measures, some scientific literature argues that subjective measures offer multiple advantages. Notably, they

Table 1
Data definitions of explicative variables.

Thematic area	Dynamic factor	Variable name	Description	Source
Economic and social conditions	Eco	*pop*	Population on 1 January (absolute value)	Eurostat
		gini	Gini index	Eurostat
		health	Healthy life years (in absolute value at birth)	Eurostat
		pov	Population at risk of poverty (% over the population)	Eurostat
		educ	Population with tertiary education (% over the population)	Eurostat
		emp	Employment rate (% over the population)	Eurostat
Environmental degradation	Env	*ghg*	Greenhouse gases (thousand tonnes)	Eurostat
		ghg_pc	Per capita greenhouse gases (thousand tonnes on total population)	Eurostat
		waste	Generation of waste per GDP unit (kilograms per thousand euro)	Eurostat
		bovine	Bovine population (thousands of animals)	Eurostat
Housing conditions	Hou	*hous_costs*	Share of housing costs in disposable household income (percentage)	EU-SILC survey
		rooms	Average number of rooms per person (average)	EU-SILC survey
		cities	Degree of urbanisation (% over the population)	Eurostat
		overcrow	Overcrowding rate (% over the population)	Eurostat
		child	Children, from 3 years to minimum school age, in formal childcare or education program (% over the population)	Eurostat

Table 2
Descriptive statistics of variables collected for the DFA analysis.

Variable name	Description	Mean	Std, deviation	Range	Minimum	Maximum
pop	Population on 1 January	19,436,229	23,279,922	82,543,026	476,187	83,019,213
gini	Gini index	29.93	3.95	19.90	20.90	40.80
health	Healthy life years	60.86	6.20	21.60	51.40	73.30
pov	Population at risk of poverty	23.91	7.69	48.80	11.90	60.70
Educ	Population with tertiary education	25.95	7.64	32.90	9.90	42.80
Emp	Employment rate	44.47	4.15	20.05	31.93	51.97
Ghg	Greenhouse gases	161,400	211,496	969,656	4859	974,515
ghg_pc	Per capita greenhouse gases	8.66	3.97	24.44	1.42	25.86
Waste	Generation of waste per GDP unit	3392	4433	19,840	188	20,028
Bovine	Bovine population	118.73	140.45	756	16	772
hous_costs	Share of housing costs in disposable household income	21.59	5.58	42.50	0.00	42.50
Rooms	Average number of rooms per person	1.62	0.40	1.50	0.90	2.40
Cities	Degree of urbanisation	38.02	10.83	62.90	13.00	75.90
Overcrow	Overcrowding rate	11.83	7.62	41.30	0.50	41.80
Child	Children, from 3 years to minimum school age, in formal childcare or education program	19.02	14.87	69.00	0.00	69.00

facilitate the apprehension of the sensory manifestations of material deprivation as discerned by individuals, as elucidated by Fahmy et al. [50]. Furthermore, Alvarez and Tol [51] underscore the utility of subjective measures in ascertaining the prevalence and degree of intensity associated with EP.

To fulfil the aims of this study, it is imperative to secure data that is amenable to cross-country comparisons within the diverse European nations. Nonetheless, as articulated by Thomson et al. [52], a conspicuous challenge looms, characterized by the absence of standardized household-level microdata about parameters encompassing energy expenditure, energy consumption, and energy efficiency, which exhibit significant variability across European Union (EU) member states. Consequently, scholars predominantly depend on harmonized data that pertain to the outcomes of EP, such as the capacity to maintain suitable indoor thermal conditions during the winter season, recorded by the EU Survey on Income and Living Conditions (EU-SILC) (e.g., [9,13]), which collects timely and comparable cross-sectional and longitudinal multidimensional microdata, providing an initial, albeit subjective, measure of the degree of energy hardship.

Eurostat systematically monitors these subjective indicators, and, in the light of these definitions, we select the percentage of the population reporting that they cannot keep their homes adequately warm (*enp*) as the outcome variable.

Eurostat provides two additional detailed indicators of this variable: the percentage of the population placed below 60 % of median equivalised income (*enp_below*) and the percentage of the population placed above 60 % of median equivalised income (*enp_above*). Analyzing the 2020 ranking of countries according to the values taken in the two indicators and the total value, we observe that the differences are insignificant (Fig. 5). For this reason, we selected the overall indicator among the three available as a proxy of EP.

Despite the known limitations, and summarized by EPAH,[3] this indicator is commonly applied in research on EP [9]. It is a proxy of deprivation, additional and independent from the standard dimensions of poverty, even though it is often combined with income poverty. This happens because it is usually associated with four basic conditions: i) energy inefficient housing ii) high energy prices, iii) low income, and iv) individual behaviour. Anyway, as recently suggested by Bouzarovsky et al. [53], *enp* goes beyond individual poverty since a household with an income just above the poverty threshold and a job could not be able to keep its house adequately warm, even if it cannot be considered at risk of poverty.

EP is measured in multiple dimensions [54]; however, since the pioneering approach of Healy and Clinch [55], *enp* has often been used as an indicator of the phenomenon [56]. It represents the outcome variable in comparative studies between countries [57] and those assessing the impact of energy policy effects [7].

The three estimated dynamic factors (*x*), lagged of one year, are used in a panel analysis of the determinants of EP together with exogenous variables accounting for the business cycle, prices, and energy transition. Moreover, to correct for possible endogeneity problems as well as the presence of unobserved global factors, we look at a dynamic factor model in which we apply the Baltagi [58] instrumental variables estimator. Then, the estimated model is:

$$enp_{it} = \alpha_i + \sum_{k=1}^{3} \beta_k x_{it-1}^k + \boldsymbol{\gamma r}_{it} + u_{it}. \tag{3}$$

where $t = 1, \ldots, T$ is the time span (2007–2020), α_i is the individual (country), time-invariant, fixed effect, $\boldsymbol{r}$ is the matrix containing the exogenous regressors while u_{it} is the disturbance with mean equal to 0. Among the exogenous regressors, to take the impact of the business cycle, the gross domestic product index (*gdp_index*), provided by Eurostat, for the sample countries is used in the model. The electricity price (*elprice*) for households (the average national price in Euro per kWh including taxes and levies for medium size household consumers) is inserted to assess the impact of the price on EP, as proxy of energy prices. Finally, to proxy the transition to green generation, a specific ET indicator (*trans*) was developed as the difference between the share of energy fed into the national energy grid generated from non-renewable sources and the share generated from renewable sources. The indicator is inserted to measure this paper's primary research question: investigate the role of green energy transition in mitigating energy poverty.

So, in line with Eq. (2), Eq. (3) becomes:

$$enp_{it} = \alpha_i + \sum_{k=1}^{3} \beta_k x_{it-1}^k + \gamma_1 gdp\_index_{it} + \gamma_2 elprice_{it} + \gamma_3 trans_{it} + u_{it} \tag{4}$$

Table 3 reports the descriptive statistics of the outcome variable and the exogenous regressors.

Moreover, we test the order of integration in the series considered trough the Levin-Lin-Chu panel data unit-root test (LLC) [59] and the Pesaran's Panel Unit Root Test in the Presence of Cross-Section Dependence (CIPS) [60]. Both tests indicate that the null hypothesis on the presence of unit root in panel data cannot be accepted (Table 4).

[3] https://energy-poverty.ec.europa.eu/about-us/news/inability-keep-home-adequately-warm-indicator-it-enough-measure-energy-poverty-2023-02-03_en.

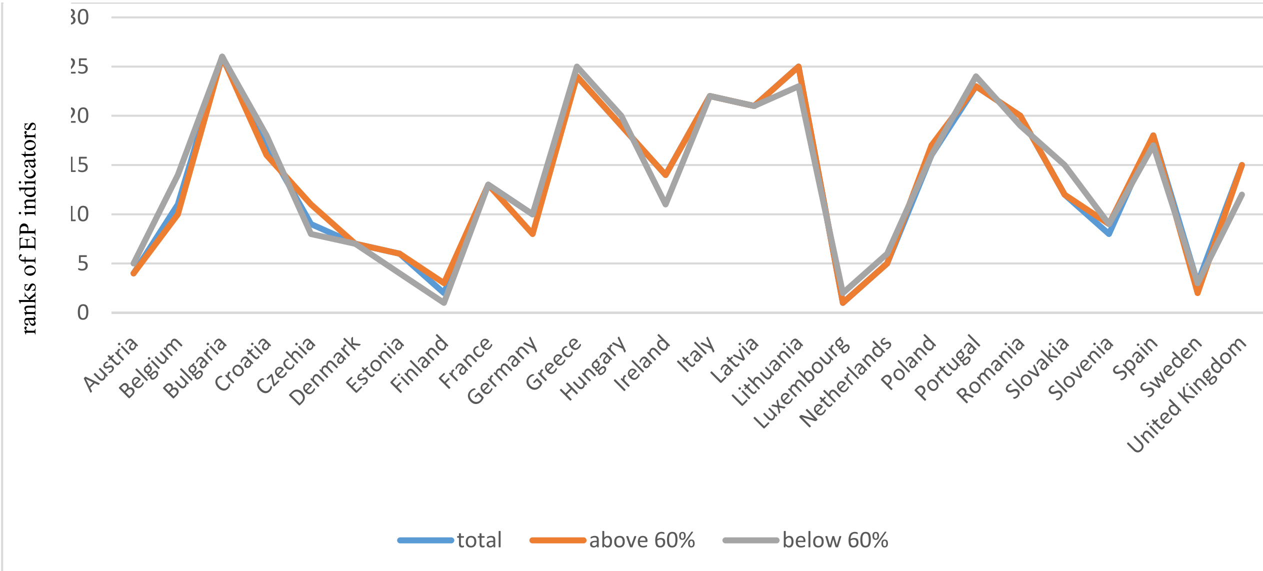

Fig. 5. European countries' ranking of energy poverty indicators.

Table 3
Descriptive Statistics of outcome variable and exogenous regressors.

Variable name	Description	Mean	Std. deviation	Range	Minimum	Maximum
enp	Population reporting that they cannot keep their homes adequately warm	10.2	10.44	45.02	1.32	46.34
gdp_index	Gross domestic product index	107.76	7.64	38.43	89.68	128.11
elprice	Households' electricity prices	0.19	0.04	0.14	0.12	0.26
trans	Energy transition	61.34	22.32	90.07	0	90.07

Table 4
Panel unit root tests statistics.

Variable name	Description	LLC	CIPS
eco	Economic and social conditions dynamic factor	−10.384	0.000
env	Environmental degradation dynamic factor	−14.441	0.000
hou	Housing conditions dynamic factor	−5.293	0.000
gdp_index	Gross domestic product index	−8.410	0.000
elprice	Households' electricity prices	−4.426	0.000
trans	Energy transition	−2.864	0.002

4. Results and robustness

4.1. Results

The coefficient estimates of the model in Eq. (4) have been obtained by using the instrumental variables estimator. The results are in Table 5. The coefficients are all significant and in line with the expected results. The estimates are robust. The Wald-F test leads to the rejection of the null hypothesis that the slope coefficients of the model are jointly equal to zero. In addition, the individual effects can be considered robust since there is no significant serial correlation in idiosyncratic errors (alternative hypothesis of the panel Durbin Watson test), and since the alternative hypothesis of the presence of cross-sectional correlation between individuals (countries), tested through the Pesaran cross-sectional dependence test (CD test), can be rejected.

The dynamic factor of the economic and social conditions thematic area, *eco*, summarizes a 6-time series ($m = 1$; $k = 6$), and it is significant and positive. Many studies investigated the EP determinants (e.g., [7]). Recently, Igawa and Managi [61] showed the economic development and EP improving common trend, while Barrella et al. [62] assessed the effectiveness of household heating allowances in reducing EP. Therefore, since the *eco* dynamic factor develops a synthetic indicator of worsening the socioeconomic conditions, the positive coefficient is in line with these well-recognized results and reveals that the country's economic development level, income inequality, and household-level socioeconomic factors affect EP. The most explicative dynamic factor of environmental degradation, *env*, which summarizes 4-time series ($m = 1$; $k = 4$) is significant and negative. It is a synthetic indicator derived from a panel of variables related to pollutant emissions and waste production to improve environmental quality and reduce pollutant emissions.

Table 5
Fixed model estimates.

Variable name	Description	Coefficient	Std error	p-Value
eco	Economic and social conditions dynamic factor	0.211	0.106	0.047
env	Environmental degradation dynamic factor	−0.638	0.127	0.000
hou	Housing conditions dynamic factor	0.278	0.104	0.008
gdp_index	Gross domestic product index	−0.136	0.023	0.000
elprice	Households' electricity prices	29.239	10.041	0.004
trans	Energy transition	0.247	0.049	0.000

Model tests	
Wald F	0.000
Panel DW test	0.418
Pesaran CD test	0.553

In consideration of recent research papers showing how energy cleanability positively affects EP [63] while the rate of carbon emission significantly intensifies the EP [64], the indirect and significant relationship of the indicator with the outcome variable is a signal confirming the negative influence of environmental degradation on the EP experience. Therefore, EP reduction can be achieved through increased clean energy generation [65] and reduced greenhouse gas emissions [66].

The third dynamic factor *hou* summarizes four variables ($m = 1$; $k = 4$) identifying households' restraints due to the inability to afford house maintenance associated with the overcrowding rates. It is directed related to EP. Housing overcrowding is commonly associated with EP conditions. This indicator's coefficient is in line with outcomes from previous studies [67,68], emphasizing that inadequate housing conditions lead to a higher risk of EP for EU households.

Income is one of the main drivers of EP; many scholars recently demonstrated the inverse relationship between GDP and EP [69]. This link confirms that the economic recession phases affected EP conditions in Europe. For this reason, the GDP index was included as an exogenous regressor in the model specification and the synthetic indicators expressed by the dynamic factors. In this way, we can estimate the elasticity of EP resulting from cyclical fluctuations. As expected, in this model specification, the outcome variable follows a countercyclical pattern: a negative and significant sign of *gdp_index* coefficient indicates that during the economic growth phases, the trend is for a general reduction in EP; the opposite occurs during recessions.

Energy prices also increase EP. Rising energy prices have a significant impact on households, especially those who are already in EP. This happens because the effects of energy expenditures on total household expenditures are highest in lower-income families. EP is generally associated with increased energy prices [70]. Therefore, in line with some recent findings [33] that highlighted, for a sample of 30 European countries in 2005–2018, how reductions in energy prices have been beneficial against EP, the coefficient of *elprice* variable is positive and significant. *Elprice* report the average national price in Euros per kWh for medium-sized household consumers, including taxes and levies, to measure household electricity prices. As expected, the results indicate that countries with higher energy prices face exacerbated energy poverty problems. Recently, some scholars started to research the linkage between the different types of energy sources and energy poverty, as well as between energy transition and energy poverty. Some demonstrated that developing the renewable energy industry alleviates EP, especially in European countries [71]. One of the aims of this work is to assess the impact on EP of the transition from polluting to green energies among the exogenous regressors; an indicator measuring the current level of the energy transition to cleaner energy sources of countries has been included. This variable, *trans*, measures the difference between the share of energy generated from non-renewable sources fed into the grid and the share generated from renewable sources. As constructed, for each country, the higher it is, the more this indicates the lag in the transition to green types of energy generation. The positive and significant sign of the estimated coefficient, in line with the first experimental studies on this linkage [72], confirms that transitioning to green energy could potentially reduce EP shocks. As a result, the slower the transition of a technological system from polluting to clean energy, the higher the incidence of EP and vice versa.

4.2. Robustness check

The measure of EP remains controversial in the literature (a comprehensive review of the current concepts and indicators is in Castano-Rosa et al. [2]). For this reason, it is essential to test the robustness of the model and the appropriateness of the explanatory variables. Following the Thomson and Snell [73] approach, we include the proposed multiple EP indicators as outcome variables in the model specification Eq. (4). Each indicator is built as a weighted average between *enp* and two different variables, both selected from the EU-SILC Survey, commonly used as indicators of EP. The first one, ***arrears***, measures the share of households with dependent children who faced difficulties in paying utility bills on time; the second *housedep* measures the percentage of households claiming severe housing deprivation.

Table 6 summarizes the weights applied to the three variables combined to obtain the four EP indicators, while Table 7 contains the estimated coefficients using the four indicators as the outcome of the model specification (Eq. (4)).

Compared with the benchmark specification (reported in Table 5 and in the first column of Table 7), the estimated coefficients of the specifications, which use multiple indicators, do not change substantially in the strengths and signs. According to the evidence from the Thomson and Snell [73] pioneering paper, the same considerations apply whether *enp* or a multiple indicator is used. This result is comforting regarding the robustness of the model and the appropriateness of the selected explanatory variables.

Although the model is built for all countries, there might be differences across countries as the rate of energy poverty varies a lot, as shown in Fig. 4. Regarding country-specific effect, heterogeneity among nations has been tested through the Lagrange multiplier tests (LM test) on the residuals of the pooling model. The results for each specification suggest that the alternative hypothesis of significant country-specific effects cannot be rejected, confirming the need for a fixed effects specification.

5. Energy poverty outlooks

The paper aims to investigate the effect of the energy transition on EP to assess if countries that fully support a path toward a green energy transition better handle the negative EP consequences of political and economic crises. Subsequently, as a second research question, it aims to provide a picture of the energy poverty outlook of European countries in the next five years. The biggest challenge to making these predictions is the lack of post-2020 data. Based on the dynamic factor model previously estimated, the empirical approach enables a forward projection of the multidimensional features of the energy poverty's determinants overcoming this hurdle. Moreover, the consequences of the recent energy crisis on the green transition processes started in European countries are unknown; in the remainder of the section, a scenario analysis will be carried out, assuming three possible paths toward the energy transition[4]:

i) Conservative. This scenario assumes that generation capacity from renewable sources will not replace fossil fuels over the next five years;
ii) Intermediate. This scenario assumes that renewable generation capacity linearly replaces generation from fossil power plants;
iii) Exponential. Similar to the previous scenario, but assuming an exponential substitution growth rate.

Under the scenarios developed, the expected value of EP for a generic

Table 6
Weighting scheme of alternative EP indicators.

Variable name	Weights
EP(2)	0.5 * *enp* + 0.25 * *arrears* + 0.25 * *housedep*
EP(3)	0.25 * *enp* + 0.5 * *arrears* + 0.25 * *housedep*
EP(4)	0.25 * *enp* + 0.25 * *arrears* + 0.5 * *housedep*
EP(5)	0.33 * *enp* + 0.33 * *arrears* + 0.33 * *housedep*

[4] Clearly, the three proposed scenarios represent a simplification of the much more nuanced realities. However, they allow for the analysis of trends based on a variation that can be represented by simple mathematical functions.

Table 7
Fixed model comparison estimates (p-values in italic).

Variable name	Description	*enp*	*EP(2)*	*EP(3)*	*EP(4)*	*EP(5)*
eco	Economic and social conditions dynamic factor	0.211	0.175	0.188	0.126	0.161
		0.047	*0.015*	*0.004*	*0.036*	*0.012*
env	Environmental degradation dynamic factor	−0.638	−0.442	−0.330	−0.359	−0.374
		0.000	*0.000*	*0.000*	*0.000*	*0.000*
hou	Housing conditions dynamic factor	0.278	0.200	0.196	0.127	0.173
		0.008	*0.005*	*0.002*	*0.032*	*0.006*
gdp_index	Gross domestic product index	−0.136	−0.143	−0.166	−0.128	−0.144
		0.000	*0.000*	*0.000*	*0.000*	*0.000*
elprice	Households' electricity prices	29.239	20.387	24.818	7.105	17.262
		0.004	*0.003*	*0.000*	*0.212*	*0.004*
trans	Energy transition	0.247	0.154	0.101	0.115	0.122
		0.000	*0.000*	*0.001*	*0.000*	*0.000*
LM test		39.240	39.937	40.773	39.410	40.179
		0.000	*0.000*	*0.000*	*0.000*	*0.000*

year $t+h$. with $h = 1\ldots$, n is conditioned on the set of information, $E(X)$, and exogenous regressors (r) that is available at time t:

$$E(Y_{t+h}) = \boldsymbol{\beta}' E(\boldsymbol{X}) + \boldsymbol{\gamma}' E(\boldsymbol{r}) + E(u_t) = \beta' E(X) \tag{5}$$

because $E(u_t) = 0$ by construction.

The explicative variables of the specification in Eq. (5) include the forecasted dynamic factors that follow an autoregressive path and the transition process is simulated through a stepwise procedure for the years 2021–2027. In the stepwise approach, for a generic $t+h$ year ($t = 2020$; $h = 1, \ldots, 7$), each $t+h$-1 dynamic factor was estimated according to the autoregressive process reported in Eq. (6). The $t+h$ expected GDP index and price level are obtained employing IMF and World Bank estimates. At the same time, for the energy transition indicator, the t observed value was used in each step of the procedure:

$$\begin{aligned}
E(enp)_{i2021} &= \alpha_i + \beta_1 eco_{i2020} + \beta_2 env_{i2020} + \beta_3 house_{i2020} + \gamma_1 E(gdp_index)_{i2021} + \gamma_2 E(elprice)_{i2021} + \gamma_3 trans_{i2020} \\
E(enp)_{i2022} &= \alpha_i + \beta_1 E(eco)_{i2021} + \beta_2 E(env)_{i2021} + \beta_3 E(house)_{i2021} + \gamma_1 E(gdp_index)_{i2022} + \gamma_2 E(elprice)_{i2022} + \gamma_3 trans_{i2020} \\
&\vdots \\
E(enp)_{i2027} &= \alpha_i + \beta_1 E(eco)_{i2026} + \beta_2 E(env)_{i2026} + \beta_3 E(house)_{i2026} + \gamma_1 E(gdp_index)_{i2027} + \gamma_2 E(elprice)_{i2027} + \gamma_3 trans_{i2020}
\end{aligned}$$

expected values of regressors.

The forecasted 2021–2027 levels of the three dynamic factors $E(X)$ are obtained based on the autoregressive process, which by construction leads to the dynamic factors:

$$\begin{aligned}
E(X_{2021}) &= c + \varphi X_{2020} \\
&\vdots \\
E(X_{2027}) &= c + \varphi E(X_{2026}).
\end{aligned} \tag{6}$$

Concerning the other regressors, the levels of GDP, expected by the International Monetary Fund World Economic Outlook (release October 2023) and the expected electricity prices on the basis of the World Bank Commodity Price Forecasts (release October 2023), have been inserted in the specification in Eq. (5). Finally, in each of the three scenarios described above, the estimated energy transition indicator estimated on the basis of their assumptions was included.

The next sections will provide the expected values of the energy poverty indicator under the assumption that each of the three scenarios described above will be carried out.

5.1. The conservative scenario

The scenario simulates a level of generation capacity in renewable sources equal to that of 2020, the last observed year, and implies a stagnation of investments in sustainable electricity capacity. In this scenario, simulations are then obtained using (i) the dynamic factor projections, (ii) the GDP index and electricity prices forecasts, respectively provided by the IMF and World Bank, and (iii) a static green energy transition indicator. The employment of a static green energy transition indicator implies that in this scenario, the assumption is that for each year from 2021 to 2027, the level of the green energy transition will remain the same as the last observed (the 2020s).

The assumption of substantial stagnation of the green energy

The forecasts are in Table 8. They are reported for each country in terms of differences (in percentage points) between the value obtained with the assumed scenario (conservative) and the last observed value ($E(enp_{i.t+h})$- $enp_{i.2020}$). Meanwhile, Fig. 1 plots, for each country, a synthetic comparison between the last observed values of EP indicator ($t = 2020$) and the average value s average forecasted in scenario 1.

From Table 8, it becomes evident that for most countries, 2021 will be the year that will observe an increase in the share of the population reporting to be in energy poverty (about 3.2 percentage points of average increase). In this scenario of a stationary energy transition process, with the expected price levels and cyclical indicators, for most of them, even in 2022, compared to 2020, there will be higher rates of EP, which will begin to decline from 2023 onwards. The scenario 1 picture is heterogeneous; while some countries (Sweden, Finland, Ireland, Netherlands) will be less affected by repercussions and will quickly rebound (to almost eliminate EP in 2027), in some other countries (Bulgaria, Greece, Romania, Italy and Portugal), the 2021–2027 period will be characterized by higher average EP levels than those observed in 2020 (Fig. 6).

5.2. The intermediate scenario

This scenario simulates a linear increase in the energy transition process. It requires that, for each country, generation from renewable sources proceed at a speed equal to the expected value obtained from a linear regression between observed generation in 2007–2020 and the respective time reference. The assumption of a linear trend implies a constant level of investment in sustainable electricity capacity. The scenario is simulated through the same stepwise procedure performed in the previous scenario. The only difference is in the estimated value of the transition indicator, which, for each year, is replaced with the expected

Table 8
Scenario 1 - Differences (%) between the estimated values and the 2020 EP indicator.

	Δ 2021–2020	Δ 2022–2020	Δ 2023–2020	Δ 2024–2020	Δ 2025–2020	Δ 2026–2020	Δ 2027–2020
Austria	5.25	−0.23	−1.09	−1.50	−1.50	−1.50	−1.50
Belgium	3.03	−2.26	−2.70	−2.67	−2.56	−2.78	−3.09
Bulgaria	18.89	12.37	11.66	10.86	10.47	9.91	9.51
Croatia	−0.81	−2.19	−2.60	−2.52	−2.30	−2.82	−3.28
Czechia	2.30	−1.28	−1.87	−2.20	−2.20	−2.20	−2.20
Denmark	3.69	−1.82	−3.00	−3.00	−3.00	−3.00	−3.00
Estonia	0.42	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70
Finland	0.68	−1.80	−1.80	−1.80	−1.80	−1.80	−1.80
France	3.15	−1.43	−2.42	−3.47	−4.80	−4.98	−5.14
Germany	1.91	−4.46	−6.19	−7.88	−8.56	−8.92	−9.00
Greece	3.41	3.29	2.60	2.38	2.34	2.38	2.09
Hungary	7.94	2.30	1.31	0.27	−0.95	−1.46	−1.97
Ireland	−3.21	−4.20	−4.20	−4.20	−4.20	−4.20	−4.20
Italy	7.32	1.48	0.98	0.82	0.73	0.36	0.16
Latvia	7.33	1.05	0.83	0.79	0.90	0.76	0.58
Lithuania	4.33	0.12	−0.67	−1.31	−2.00	−2.35	−2.67
Luxembourg	−2.03	−3.60	−3.60	−3.60	−3.60	−3.60	−3.60
Netherlands	−1.33	−2.40	−2.40	−2.40	−2.40	−2.40	−2.40
Poland	3.38	−1.80	−1.76	−1.35	−1.03	−1.65	−2.18
Portugal	8.67	2.49	2.01	1.88	1.65	1.11	0.82
Romania	4.53	0.21	−0.55	−1.05	−1.51	−1.96	−2.40
Slovakia	0.27	−5.09	−5.70	−5.70	−5.70	−5.70	−5.70
Slovenia	1.52	−2.80	−2.80	−2.80	−2.80	−2.80	−2.80
Spain	1.70	−4.78	−5.69	−6.28	−6.84	−7.28	−7.64
Sweden	−1.67	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70
United Kingdom	2.70	−0.93	−1.71	−2.27	−3.11	−3.60	−3.96

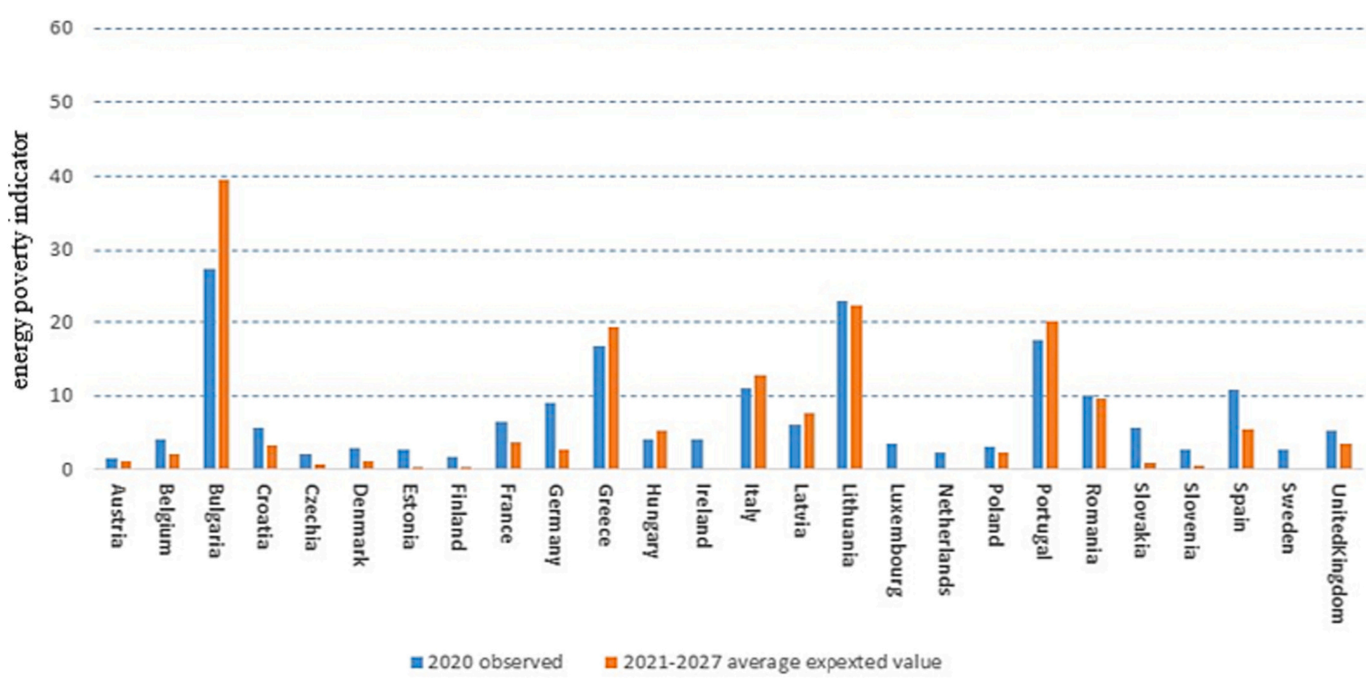

Fig. 6. Scenario 1. Comparison between 2020 observed EP indicators and 2021–2027 average forecasted values.

value according to the linear trend observed in the previous years. The simulations are based on the same conditions as the GDP index and electricity prices of the previous one.

The linear regression equation used to analyze the relationship between the energy transition indicator and the time is:

$$trans_i = b + m(t)$$

where $t = 2007, \ldots, 2020$. The estimated coefficients are then used to forecast the 2021–2027 *trans* expected values

$$E(trans_{i,2021}) = b + m(t+1)$$
$$\vdots$$
$$E(trans_{i,2027}) = b + m(t+7)$$

Consequently, the scenario 2 stepwise procedure has the following construction:

Table 9
Scenario 2 - Differences (%) between the estimated values and the 2020 EP indicator.

	Δ 2021–2020	Δ 2022–2020	Δ 2023–2020	Δ 2024–2020	Δ 2025–2020	Δ 2026–2020	Δ 2027–2020
Austria	5.54	−0.17	−1.26	−1.50	−1.50	−1.50	−1.50
Belgium	3.49	−2.11	−2.85	−3.11	−3.30	−3.83	−4.10
Bulgaria	18.52	11.52	10.33	9.04	8.16	7.12	6.23
Croatia	−0.78	−2.44	−3.14	−3.34	−3.41	−4.22	−4.96
Czechia	1.86	−2.06	−2.20	−2.20	−2.20	−2.20	−2.20
Denmark	0.36	−3.00	−3.00	−3.00	−3.00	−3.00	−3.00
Estonia	−1.19	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70
Finland	0.04	−1.80	−1.80	−1.80	−1.80	−1.80	−1.80
France	3.37	−1.51	−2.80	−4.15	−5.78	−6.27	−6.50
Germany	2.15	−4.54	−6.59	−8.60	−9.00	−9.00	−9.00
Greece	3.37	2.75	1.55	0.83	0.29	−0.17	−0.96
Hungary	7.30	1.53	0.40	−0.77	−2.12	−2.77	−3.42
Ireland	−2.24	−4.20	−4.20	−4.20	−4.20	−4.20	−4.20
Italy	7.03	0.85	0.00	−0.51	−0.95	−1.67	−2.21
Latvia	6.86	0.13	−0.56	−1.05	−1.40	−2.00	−2.64
Lithuania	3.57	−1.01	−2.18	−3.20	−4.27	−4.99	−5.70
Luxembourg	−0.82	−3.60	−3.60	−3.60	−3.60	−3.60	−3.60
Netherlands	0.59	−2.40	−2.40	−2.40	−2.40	−2.40	−2.40
Poland	3.49	−2.01	−2.27	−2.16	−2.14	−3.08	−3.20
Portugal	8.70	2.09	1.19	0.63	−0.02	−0.99	−1.70
Romania	3.77	−0.75	−1.69	−2.39	−3.04	−3.68	−4.31
Slovakia	0.93	−4.74	−5.70	−5.70	−5.70	−5.70	−5.70
Slovenia	2.16	−2.80	−2.80	−2.80	−2.80	−2.80	−2.80
Spain	2.15	−4.68	−5.93	−6.86	−7.76	−8.54	−9.24
Sweden	−0.96	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70
United Kingdom	2.23	−1.82	−3.02	−4.01	−5.27	−5.40	−5.40

$$
\begin{aligned}
E(enp)_{i2021} &= \alpha_i + \beta_1 eco_{i2020} + \beta_2 env_{i2020} + \beta_3 house_{i2020} + \gamma_1 E(gdp\_index)_{i2021} + \gamma_2 E(elprice)_{i2021} + \gamma_3 E(trans)_{i2021} \\
E(enp)_{i2022} &= \alpha_i + \beta_1 E(eco)_{i2021} + \beta_2 E(env)_{i2021} + \beta_3 E(house)_{i2021} + \gamma_1 E(gdp\_index)_{i2022} + \gamma_2 E(elprice)_{i2022} + \gamma_3 E(trans)_{i2022} \\
&\vdots \\
E(enp)_{i2027} &= \alpha_i + \beta_1 E(eco)_{i2026} + \beta_2 E(env)_{i2026} + \beta_3 E(house)_{i2026} + \gamma_1 E(gdp\_index)_{i2027} + \gamma_2 E(elprice)_{i2027} + \gamma_3 E(trans)_{i2027}
\end{aligned}
$$

The forecasted values are in Table 9. They are reported for each country in terms of differences (in %) between the value estimated in a linear trend intermediates scenario and the last observed value ($E(enp_{i,t+h})$- $enp_{i,2020}$). Fig. 6 shows the differential between the expected value in years t + h ($t = 2020$ and h > 0) and t = 2020 (last observed year).

Table 9 clearly shows that the scenario 2 EP forecasts are similar to those of the scenario 1. In this scenario, in most countries, in 2021, an increase in the share of the population reporting to be in energy poverty will be observed. However, the growth will be more mitigated (about 3 percentage points of average increase in 2021 and a similar 2020

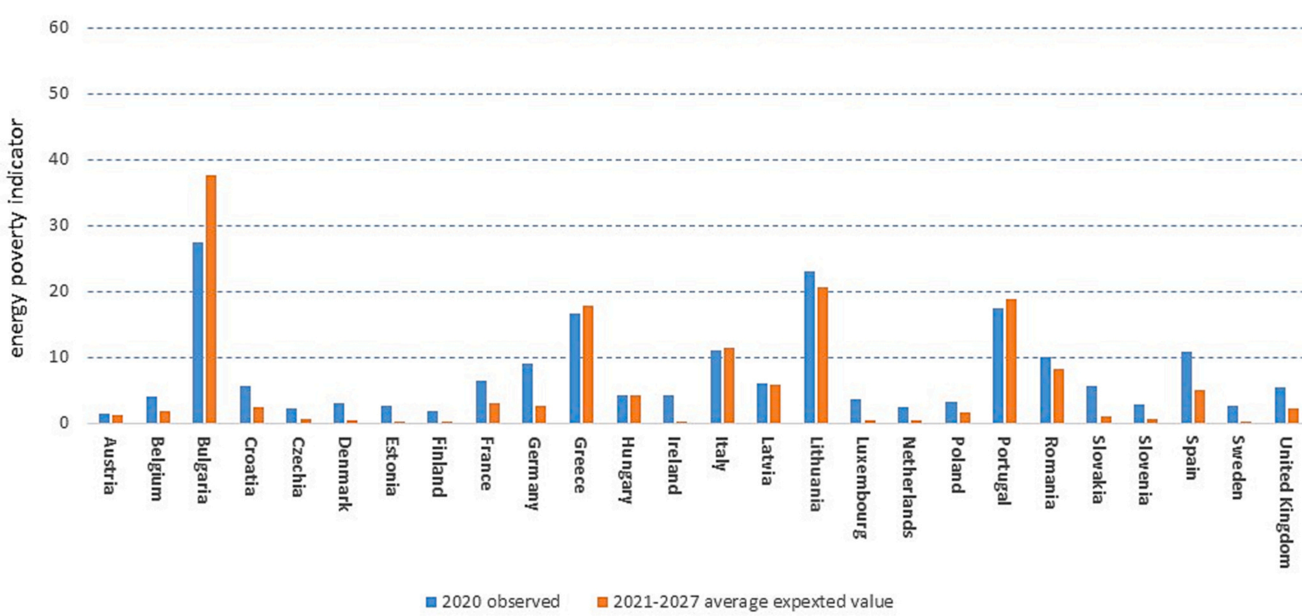

Fig. 7. Scenario 2. Comparison between 2020 observed EP indicators and 2021–2027 average forecasted values.

average values in 2022) if, in the meantime, the path toward energy transition will not be stopped entirely but will continue as fast as it has in previous years. In addition, those countries that historically experience the highest rates of EP will more quickly recover to 2020 values after the peaks of the next two years. Also, the scenario 2 picture is very heterogeneous. Still, for the countries with the most critical issues (Bulgaria, Greece, Italy, and Portugal), the 2021–2027 period will be characterized by higher average EP levels than those observed in 2020 (Fig. 7). Still, the increase will be less pronounced if they continue investing in the RES generation.

5.3. The exponential scenario

The hypothesis of exponential acceleration along the green energy transition process already undertaken is simulated through the same 2021–2027 stepwise procedure performed in the previous scenarios. This scenario is modified according to the assumption that estimated values of the green energy transition indicator are those that would be obtained if the highest variation was observed in the period 2007–2020. This assumption implies that for each year from 2021 to 2027, the level of investments allocated to green energy capacity will exponentially increase.

Even in this case, the only difference is in the estimated value of the transition indicator, which, for each year, is replaced with the value that would be obtained if each year occurred, the highest variation in terms of energy transition observed in the period 2007–2020:

$$max\Delta(trans_i) = max\left(\frac{trans_{it} - trans_{it-1}}{trans_{it-1}}\right)$$

for $t = 2008\ldots2020$.

The $max\Delta(trans_{it})$ are then used to forecast the 2021–2027 *trans* expected values

$$E(trans_{i.2021}) = trans_{i.2020}(1 + max\Delta(trans_i))$$
$$\vdots$$
$$E(trans_{i.2027}) = trans_{i.2026}(1 + max\Delta(trans_i))$$

Consequently, the scenario 3 stepwise procedure has the following construction:

$$E(enp)_{i2021} = \alpha_i + \beta_1 eco_{i2020} + \beta_2 env_{i2020} + \beta_3 house_{i2020} + \gamma_1 E(gdp\_index)_{i2021} + \gamma_2 E(elprice)_{i2021} + \gamma_3 E(trans)_{i2021}$$
$$E(enp)_{i2022} = \alpha_i + \beta_1 E(eco)_{i2021} + \beta_2 E(env)_{i2021} + \beta_3 E(house)_{i2021} + \gamma_1 E(gdp\_index)_{i2022} + \gamma_2 E(elprice)_{i2022} + \gamma_3 E(trans)_{i2022}$$
$$\vdots$$
$$E(enp)_{i2027} = \alpha_i + \beta_1 E(eco)_{i2026} + \beta_2 E(env)_{i2026} + \beta_3 E(house)_{i2026} + \gamma_1 E(gdp\_index)_{i2027} + \gamma_2 E(elprice)_{i2027} + \gamma_3 E(trans)_{i2027}$$

The forecasted values are in Table 10. They report, for each country, the variation (%) between the estimated values and the last observed value ($E(enp_{i.t+h})$- $enp_{i.2020}$); Fig. 3 plots, for each country, a synthetic comparison between the last observed values of EP indicator ($t = 2020$) and the average forecasted value.

Scenario 3 looks significantly different from the previous two. Table 10 clearly shows that in 2021, fewer countries will be affected by the severe consequences in terms of EP if there is a strong acceleration in the path leading toward the green energy transition. Moreover, even for the most vulnerable ones, the increase will be more mitigated (about 2 percentage points of the average increase in 2021 and an average reduction in 2022 of about 2.2 percentage points). Scenario 3 shows a less heterogeneous pattern and, in this scenario, a worsening of conditions, compared to the 2020 state, would occur only for one country (Bulgaria). This is a borderline case, the most optimistic scenario available, but it is not an unachievable requirement. If this condition were to be achieved, it would ensure the eradication of EP for many

Table 10
Scenario 3 - Differences (%) between the estimated values and the 2020 EP indicator.

	Δ 2021–2020	Δ 2022–2020	Δ 2023–2020	Δ 2024–2020	Δ 2025–2020	Δ 2026–2020	Δ 2027–2020
Austria	4.11	−1.50	−1.50	−1.50	−1.50	−1.50	−1.50
Belgium	1.64	−4.10	−4.10	−4.10	−4.10	−4.10	−4.10
Bulgaria	17.71	10.12	8.43	6.75	5.54	4.25	3.18
Croatia	−1.92	−4.28	−5.55	−5.70	−5.70	−5.70	−5.70
Czechia	1.53	−2.20	−2.20	−2.20	−2.20	−2.20	−2.20
Denmark	2.37	−3.00	−3.00	−3.00	−3.00	−3.00	−3.00
Estonia	−0.91	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70
Finland	0.15	−1.80	−1.80	−1.80	−1.80	−1.80	−1.80
France	2.20	−3.26	−5.08	−6.50	−6.50	−6.50	−6.50
Germany	0.96	−6.30	−8.86	−9.00	−9.00	−9.00	−9.00
Greece	2.44	1.42	−0.12	−1.12	−1.88	−2.52	−3.44
Hungary	6.60	−0.27	−2.41	−4.20	−4.20	−4.20	−4.20
Ireland	−4.20	−4.20	−4.20	−4.20	−4.20	−4.20	−4.20
Italy	6.31	−0.46	−1.84	−2.82	−3.66	−4.74	−5.59
Latvia	6.46	−0.49	−1.24	−1.68	−1.89	−2.27	−2.64
Lithuania	3.40	−1.67	−3.25	−4.61	−5.97	−6.93	−7.82
Luxembourg	−3.60	−3.60	−3.60	−3.60	−3.60	−3.60	−3.60
Netherlands	−2.40	−2.40	−2.40	−2.40	−2.40	−2.40	−2.40
Poland	1.72	−3.20	−3.20	−3.20	−3.20	−3.20	−3.20
Portugal	7.30	−0.01	−1.42	−2.33	−3.20	−4.27	−4.99
Romania	3.71	−1.39	−2.86	−4.04	−5.13	−6.16	−7.15
Slovakia	−1.84	−5.70	−5.70	−5.70	−5.70	−5.70	−5.70
Slovenia	0.18	−2.80	−2.80	−2.80	−2.80	−2.80	−2.80
Spain	0.22	−7.60	−9.70	−10.90	−10.90	−10.90	−10.90
Sweden	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70	−2.70
United Kingdom	1.99	−2.32	−3.75	−4.94	−5.40	−5.40	−5.40

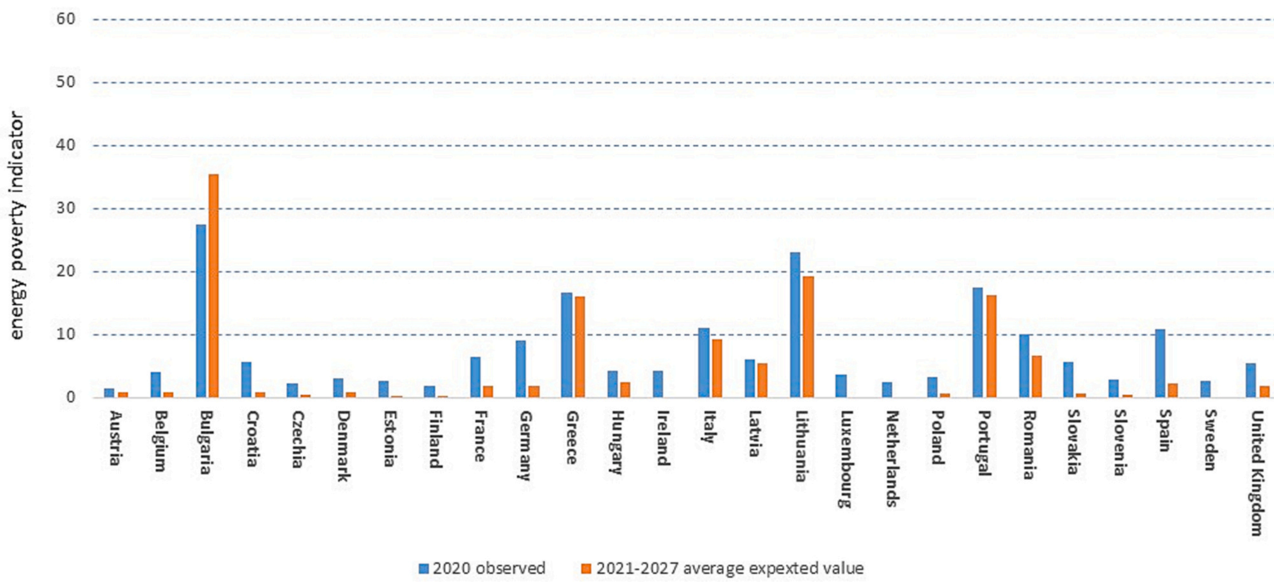

Fig. 8. Scenario 3. Comparison between 2020 observed EP indicators and 2021–2027 average forecasted values.

countries and the improvement for most of them. In this scenario, the 2021–2027 period will be characterized by lower average EP levels than those observed in 2020 (Fig. 8).

6. Conclusion and policy implications

The COVID-19 pandemic and the Russia-Ukraine crisis instigated an inflationary spiral primarily driven by escalating energy (and food) prices, which significantly adversely affected economically vulnerable households. In addition, the energy crisis triggered by the reduction of gas supplies destined for European countries as a result of international sanctions imposed on Russia has accelerated the need for an energy transition: The European Commission has called for member countries to invest more in renewable sources, to reach 45 % of total green generation by 2030 [14].

With this in mind, this paper seeks to contribute to the debate on the relationship between energy transition and EP within EU Member States. The purpose is to provide forecasts of EP trends in the immediate future up to the year 2027. In particular, the work aims to test how the energy transition counteracts energy poverty. To achieve this goal, three different scenarios were simulated:

i) Conservative Scenario: In this scenario, it is assumed that renewable energy sources will not significantly replace fossil fuels in terms of generation capacity within the next five years.
ii) Intermediate Scenario: Under this scenario, there is projected to be a gradual, linear replacement of generation capacity from fossil power plants with renewable sources over the next five years.
iii) Exponential Scenario: This scenario is akin to the intermediate one but posits a more rapid, exponential substitution of generation capacity from fossil power plants with renewable energy sources within the same five-year timeframe.

To reach the aims, we use a comprehensive data set of 26 variables and extrapolate dynamic factors individuating three EP influencing areas: (i) economic and social conditions, (ii) environmental degradation, and (iii) housing conditions. Moreover, we considered GDP as a proxy for economic growth, electricity prices, and a specific energy transition indicator. Widuto [11] argued that energy poverty involves countries with lower GDP more, just as rising electricity prices have increased the share of vulnerable households. To test the effect of energy transition on EP, the degree of substitution of fossil sources for renewable ones was considered. The estimated coefficients are all significant and in line with the expected sign, confirming that the proposed multidimensional latent factors and all the other exogenous regressors affect EP in EU countries. There is a widespread and heterogeneous picture of EP in Europe. In some countries, the issue is marginal or ready to be overcome; in others, there are still high rates of energy poverty, and the energy transition can reduce the incidence of energy poverty.

The three scenarios showed that the energy transition makes it possible to reduce the share of households reporting themselves in a condition of EP, even if it occurs with different effects depending on the assumed pathway.

Focusing on the conservative scenario, the incidence of energy poverty will decrease not due to the effect of the transition but because of the dynamics of economic growth and energy prices, as projected by the World Bank and the IMF, respectively. Countries traditionally with strong economies (such as France and Germany) or those with already low levels of energy poverty (Sweden and Finland) will experience a significant decrease in the percentage of households reporting difficulties in heating their homes. On the other hand, the most economically depressed countries or those characterized by high levels of energy poverty will not experience significant benefits. The effects of the transition will be more pronounced in the other two scenarios, where, while maintaining the characteristics of the first scenario, a substantial reduction in the incidence of energy poverty will be observed.

In general, it is observed that the coming years should see an average reduction in the incidence of energy poverty in European countries, although there are clear signs that it will still lead to an increase in some nations. The energy transition, including the reduction in electricity costs (e.g., [74,75]), will bring the expected benefits to families in need, which an anticipated phase of economic expansion will amplify.

As a consequence of the mentioned conditions, international, European, and national authorities should recognize that country-specific interventions are needed to prevent further increases in inequality as EP increases. It is acknowledged that actions to tackle EP may vary depending on the context and peculiarities of each country. Therefore, the effectiveness of countering actions will be based on the ability to tailor policies to the local needs and conditions.

As demonstrated, decisive action toward energy transition is certainly helpful in reducing the impact of EP. Clearly, a linear increase is not enough, but substantial investment is needed that will lead to exponential growth in the amount of electricity produced from renewables that gradually replaces that portion generated from traditional sources. Moreover, investments in the energy transition will, over the years, lead to lower electricity rates (e.g., [76]). In the meantime, it would be helpful to consolidate all the diverse electricity and gas benefits into a singular tool linked to each household's individualized risk of EP. This is a highly ambitious target, considering the variations in measurement criteria and the definition of EP across the European Union [13].

Further efforts should be devoted to improving vulnerable households' living and housing conditions [77,78]. In a historical stage marked by high energy prices, policy authorities should envision (or strengthen if already in place) energy subsidy programs to help vulnerable households improve the condition of their homes by reducing energy consumption and improving efficiency. Investing in energy efficiency and building upgrading projects can reduce households' energy consumption and, consequently, their expenditures. This can include installing thermal insulation, energy-efficient windows, more efficient boilers, and adopting smart technologies to control consumption. Proposals for reducing energy consumption should consider that a large percentage of households in the EU live in houses with inadequate insulation. This situation may be exacerbated by climate change. Previous studies, such as the one conducted by Damigos et al. [79], have shown that low-income households tend to focus on short-term rather than long-term outcomes, making them prone to make limited decisions (the so-called "discounting gap"). Therefore, implementing meaningful energy-saving programs for residential buildings could help mitigate energy poverty.

The "Recovery Plan" might play a crucial role in this perspective. Following the 2020 European Commission recommendations, these funds are expected to be allocated to support households in lowering energy expenses and achieving a better quality of life.

Our findings emphasize that the faster the energy transition, the greater the action to counter energy poverty can be. Moreover, as further policy implication, encouraging the adoption of renewable energy can help reduce long-term energy costs and improve household energy resilience. Indeed, countries less affected by energy poverty are also the ones in which the share of energy generated from renewable sources fed into the grid predominates over that generated from fossil fuels. European Commission, which increased the renewable energy generation targets, urges to simplify bureaucratic processes and strengthen support for investment in renewable energy. Policies can include financial incentives for installing solar panels, wind turbines, or other forms of clean energy generation.

The acceleration of the energy crisis due to the recent development in Russia vs. Ucraina war, which started after the pandemic period and the resulting severe economic consequences, shows a not encouraging outlook for countries. However, the current challenges can be turned into opportunities for renewable energy over the next few years. An example is offered by taking advantage of benefits from the digitization of work and other daily activities, as it could reduce traveling and the consumption of fossil energy sources [80,81].

A complementary policy strategy should envisage educating consumers on the conscious use of energy sources to reduce consumption and save money. This can include advice on reducing energy waste, using household appliances efficiently, and adopting sustainable energy habits.

A recommendation urges to promote the collaboration among stakeholders (policymakers, nongovernmental organizations, universities, research institutions, energy suppliers, and others) can help develop integrated policies and customizing solutions to address energy poverty. The synergy can lead to greater effectiveness in identifying needs and implementing targeted interventions that take into account unique country's characteristics, such as different climatic and socio-economic conditions.

6.1. Limitations and further research

Our results are based on data from 2007 to 2020. Even if it is based on a rigorous data analysis, it is subject to some limitations that can serve as starting points for further research. First, our study is based on a panel of EU member states. While sharing different energy and economic policies, these countries still do not have a single political representation. This leads to different timeframes and different implementation of recommendations coming from the European Commission.

Furthermore, the heterogeneity, including climate, across countries makes it necessary to take a tailored approach to tackling energy poverty. It also requires the availability of currently unavailable data that can help measure energy poverty. The multiplicity of measures proposed and used makes it difficult to identify common patterns to be able to direct policy action. Therefore, in the authors' research agenda, there is the intent to collect, for the countries for which will be available, individual disaggregated data, which will allow a more precise analysis by taking into account the issues related to the above-mentioned heterogeneous characteristics of the countries already accounted in this work.

CRediT authorship contribution statement

Alfonso Carfora: Data curation, Formal analysis, Methodology, Software, Writing – original draft. **Giuseppe Scandurra:** Conceptualization, Formal analysis, Methodology, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

Table A1
Descriptive statistics: variables' means (2007–2020).

	EP	trans	gdp_index	elprice	bovine	waste	ghg	ghg_pc	pov	emp	Pop	gini	educ	health	hous_costs	rooms	cities	overcrow	child
Austria	2.69	35.18	105.13	0.18	1957	56.50	76,154	9.00	18.38	48.37	8,544,188	27.35	22.81	58.81	18.31	1.76	32.39	12.90	17.37
Belgium	6.11	85.01	104.67	0.21	2463	93.36	121,557	11.14	20.64	41.18	11,103,534	26.16	32.39	63.71	21.04	2.24	37.80	3.92	1.35
Bulgaria	46.34	66.65	106.51	0.19	563	438.57	49,336	6.82	43.26	42.75	7,265,314	36.61	22.21	65.05	23.20	1.14	43.09	14.36	27.56
Croatia	8.53	46.73	103.26	0.19	442	72.36	19,889	4.78	28.82	38.94	4,224,365	30.49	17.87	58.79	23.08	1.11	29.04	15.71	50.84
Czechia	4.82	73.81	107.72	0.22	1351	75.64	130,494	12.48	13.98	48.03	10,506,203	24.76	17.79	62.67	23.64	1.47	32.01	14.14	25.07
Denmark	3.19	45.16	106.67	0.21	1568	38.50	56,937	10.56	17.23	48.73	5,632,083	26.93	29.55	60.98	30.57	1.99	33.92	10.08	5.70
Estonia	2.60	47.76	118.33	0.16	248	687.43	16,846	12.84	23.49	47.57	1,325,463	32.19	32.56	55.56	16.85	1.53	47.84	12.71	8.01

(*continued on next page*)

Table A1 (*continued*)

	EP	trans	gdp_index	elprice	bovine	waste	ghg	ghg_pc	pov	emp	Pop	gini	educ	health	hous_costs	rooms	cities	overcrow	child
Finland	1.60	26.77	103.18	0.12	889	96.79	44,035	8.36	16.73	45.82	5,422,928	25.79	34.26	53.56	17.79	2.01	32.75	16.73	19.16
France	5.62	71.92	104.29	0.14	19,102	46.79	440,684	6.82	18.33	39.98	65,681,032	29.35	29.22	63.57	18.11	1.95	44.94	10.32	5.41
Germany	4.80	72.10	106.86	0.26	12,431	53.14	889,166	11.05	19.97	48.88	81,778,870	29.76	23.99	61.29	29.86	1.93	41.01	11.46	13.39
Greece	22.05	71.58	89.68	0.17	621	99.71	103,318	9.74	31.84	36.29	10,932,252	33.36	24.03	65.52	32.82	1.24	40.32	10.04	26.64
Hungary	9.63	73.81	110.17	0.22	793	108.64	59,379	6.09	27.51	41.31	9,904,869	27.13	19.48	59.25	24.43	1.24	31.18	13.56	16.51
Ireland	6.07	83.43	128.11	0.20	6345	38.93	66,700	14.56	25.35	45.03	4,650,257	29.86	36.91	66.94	15.56	2.23	34.61	1.21	10.58
Italy	14.64	68.74	98.92	0.22	6295	64.50	436,432	7.51	27.31	38.04	59,824,844	32.41	14.79	64.25	17.40	1.41	39.71	7.94	8.72
Latvia	14.99	27.75	118.00	0.19	398	74.57	8788	4.18	32.77	44.87	2,036,299	35.54	26.30	53.58	19.71	1.16	44.59	27.56	23.31
Lithuania	27.66	54.89	118.65	0.19	715	119.21	13,344	4.55	29.48	44.95	2,986,787	35.41	30.99	58.08	18.06	1.42	42.51	13.09	27.01
Luxembourg	1.32	90.07	109.29	0.14	195	29.71	10,828	20.36	18.48	44.90	545,617	29.19	33.76	63.37	13.85	2.11	26.19	11.30	20.28
Netherlands	2.27	88.18	104.28	0.16	3977	65.29	199,276	11.98	15.95	50.31	16,823,282	26.68	29.99	60.86	29.26	1.89	55.96	5.46	9.74
Poland	11.01	77.48	112.44	0.24	5777	181.07	370,550	9.74	24.58	41.89	38,033,919	30.24	22.72	61.37	22.29	1.07	35.87	24.86	53.87
Portugal	26.28	45.06	98.87	0.24	1563	75.36	60,535	5.92	24.56	45.71	10,437,294	33.98	18.34	59.01	16.72	1.63	44.29	1.49	14.22
Romania	16.09	53.77	115.50	0.24	2148	199.50	92,761	4.76	39.14	43.69	20,028,436	34.87	13.66	59.31	23.76	1.03	33.01	10.20	40.21
Slovakia	5.24	77.27	109.18	0.22	461	106.36	36,297	6.82	18.70	44.79	5,412,322	24.00	17.87	54.56	21.75	1.18	23.83	19.52	26.04
Slovenia	4.56	56.70	105.14	0.18	474	89.50	15,152	7.25	17.93	46.43	2,053,373	23.81	24.53	58.25	15.34	1.43	18.85	14.53	9.09
Spain	8.54	69.72	101.37	0.23	6221	62.71	313,344	6.94	26.37	40.46	46,418,231	33.49	31.04	65.57	17.81	1.98	50.92	1.61	6.68
Sweden	1.83	−0.95	107.80	0.15	1450	51.93	19,727	2.13	17.72	49.54	9,654,752	26.36	32.21	64.67	23.04	1.90	30.84	19.76	4.73
United Kingdom	6.64	86.28	107.80	0.16	9751	60.93	544,874	8.80	23.12	47.75	64,115,429	32.53	35.29	63.76	26.96	2.11	60.94	3.07	22.93

Table A2
Descriptive statistics: variables' standard deviations (2007–2020).

	warm_up	trans	gdp_index	elprice	bovine	waste	ghg	ghg_pc	pov	emp	pop	gini	educ	health	hous_costs	rooms	cities	overcrow	child
Austria	0.72	4.31	4.70	0.01	48	11.27	2959	0.61	1.04	0.45	217,577	0.51	7.07	1.47	0.48	0.05	2.87	1.02	5.65
Belgium	2.60	5.28	5.15	0.04	70	11.45	8216	1.15	0.76	0.54	294,605	0.57	2.99	0.50	1.06	0.05	12.39	1.27	0.87
Bulgaria	14.09	8.50	7.41	0.01	23	28.89	3220	0.43	7.98	1.98	189,976	2.65	2.58	1.79	3.98	0.09	1.91	2.88	12.46
Croatia	1.36	5.30	5.22	0.02	14	10.56	2210	0.46	3.23	1.83	88,593	1.03	3.19	1.66	3.12	0.04	2.88	1.11	5.08
Czechia	1.58	5.93	9.02	0.02	18	4.77	7946	0.91	1.34	1.20	110,771	0.44	3.69	0.77	0.98	0.10	2.45	4.01	5.10
Denmark	2.15	12.75	6.49	0.02	42	2.93	9024	2.06	0.75	1.35	122,207	0.87	2.70	2.22	2.16	0.05	1.64	0.76	3.93
Estonia	0.81	8.57	12.69	0.02	10	46.32	2205	1.57	1.16	2.18	9278	1.58	2.94	1.33	1.52	0.22	6.97	10.50	2.56
Finland	0.27	9.57	3.55	0.01	26	27.02	7894	1.63	0.70	0.94	84,796	0.41	3.11	15.43	0.45	0.04	5.82	1.13	4.25
France	0.61	5.34	4.23	0.02	596	1.31	26,768	0.55	0.69	0.36	1,194,077	1.01	3.42	0.49	0.71	0.07	3.52	1.98	1.38
Germany	1.61	5.52	6.25	0.03	485	2.51	54,093	0.71	1.43	1.68	992,624	0.78	1.84	4.37	2.33	0.05	6.81	0.53	11.34
Greece	6.56	8.69	11.88	0.04	65	16.38	17,095	1.45	3.42	3.37	159,655	1.13	3.27	0.97	5.30	0.05	3.07	3.59	12.38
Hungary	3.22	4.53	10.13	0.04	87	17.49	4408	0.51	5.36	3.51	108,158	1.57	2.44	1.88	1.43	0.20	1.13	4.90	6.88
Ireland	2.24	6.82	32.52	0.02	237	17.86	3498	1.31	3.55	3.05	165,906	0.99	3.85	1.74	1.70	0.08	0.95	0.58	3.55
Italy	3.58	6.18	3.41	0.02	182	5.61	58,114	1.14	1.83	0.80	859,044	0.58	1.94	2.48	1.05	0.04	4.61	1.38	3.44
Latvia	5.63	8.20	10.49	0.04	15	14.96	2079	1.27	4.57	2.51	100,728	0.94	4.42	1.31	1.43	0.12	1.67	7.86	8.46
Lithuania	4.19	6.73	13.38	0.03	50	34.06	2666	0.89	2.56	3.10	159,075	1.76	4.90	1.32	2.19	0.23	0.59	7.82	9.55
Luxembourg	0.94	5.43	9.68	0.01	5	5.69	817	3.37	1.70	1.63	48,587	1.59	5.70	2.24	0.20	0.09	14.47	1.34	7.76
Netherlands	0.53	5.57	4.93	0.02	201	1.73	9538	0.75	0.71	0.97	310,265	0.94	3.25	1.48	1.07	0.04	7.42	1.58	3.28
Poland	6.03	5.49	15.47	0.02	305	9.13	8961	0.23	5.00	1.15	60,820	1.53	4.29	0.96	0.84	0.06	3.12	2.02	10.94
Portugal	6.67	7.57	3.85	0.04	85	20.56	6808	0.72	2.27	2.08	121,319	1.51	4.45	2.04	1.64	0.09	0.56	0.57	6.33
Romania	6.76	3.97	14.26	0.03	294	94.35	11,956	0.59	5.08	1.03	489,119	1.48	2.05	1.34	7.59	0.06	3.44	1.63	9.14
Slovakia	1.05	5.77	10.45	0.02	20	21.83	2751	0.58	2.07	1.65	26,824	1.64	3.83	1.75	3.24	0.04	2.06	2.07	6.45
Slovenia	1.14	3.06	7.03	0.02	10	13.24	2739	1.28	1.87	1.82	22,111	0.60	4.29	3.18	1.00	0.21	0.55	8.45	3.47
Spain	1.65	6.01	4.63	0.04	296	3.29	37,883	0.99	1.69	2.66	568,598	0.93	3.01	2.20	1.07	0.04	0.64	0.44	3.40
Sweden	0.53	9.37	8.60	0.01	35	7.10	4774	0.57	1.22	0.59	383,479	1.19	4.24	18.95	1.28	0.04	8.54	1.99	1.68
United Kingdom	1.71	7.26	6.76	0.02	173	8.87	73,152	1.47	0.82	0.91	1,899,091	1.05	4.24	1.66	3.14	0.13	5.81	2.77	9.40

Table A3
Descriptive statistics: variables' minimum values (2007–2020).

	warm_up	trans	gdp_index	elprice	bovine	waste	ghg	ghg_pc	pov	emp	Pop	gini	educ	health	hous_costs	rooms	cities	overcrow	child
Austria	1.50	26.91	98.20	0.16	1855	48.00	71,888	8.30	16.70	47.37	8,282,984	26.20	14.60	56.90	17.30	1.70	29.70	11.10	11.20
Belgium	3.90	74.00	97.30	0.15	2335	72.00	112,974	10.05	18.90	40.50	10,584,534	25.10	28.10	62.40	19.70	2.20	27.40	1.60	0.00
Bulgaria	27.50	53.36	96.60	0.18	527	389.00	43,902	5.92	32.10	40.04	7,000,039	33.20	18.50	63.20	18.20	1.00	39.50	10.50	6.50
Croatia	5.70	37.95	96.95	0.15	414	60.00	17,305	4.10	23.20	35.76	4,076,246	28.30	13.40	56.10	18.20	1.10	24.50	14.10	43.20
Czechia	2.20	65.39	97.80	0.19	1319	71.00	119,315	11.32	11.90	46.47	10,254,233	24.00	11.60	61.40	22.40	1.30	29.90	9.50	19.10
Denmark	1.50	25.96	98.20	0.18	1500	35.00	46,653	8.04	15.90	47.05	5,447,084	25.10	26.00	58.00	27.70	1.90	31.90	8.80	1.00
Estonia	1.10	36.54	97.80	0.12	235	646.00	13,257	9.94	21.70	42.60	1,314,870	30.50	27.50	52.30	14.90	1.20	42.00	4.50	5.10
Finland	1.10	12.40	97.10	0.10	835	70.00	35,392	6.61	15.60	44.53	5,276,955	25.20	30.00	0.00	16.60	2.00	25.70	14.60	11.80
France	4.60	61.78	98.10	0.11	17,816	45.00	405,260	6.05	17.00	39.31	63,645,065	26.60	24.40	62.60	17.00	1.80	35.90	8.00	3.30
Germany	2.50	61.38	96.10	0.20	11,302	48.00	793,335	9.56	17.40	46.15	80,222,065	28.30	20.40	56.50	27.30	1.90	34.80	10.60	7.90
Greece	13.80	56.50	77.31	0.11	530	79.00	82,150	7.66	27.60	31.93	10,724,599	31.00	19.10	64.00	27.30	1.20	36.40	5.30	5.30
Hungary	4.20	67.59	99.30	0.17	682	87.00	53,037	5.38	17.80	37.27	9,772,756	24.10	15.40	56.50	21.50	1.10	29.20	5.00	8.10
Ireland	3.50	67.68	98.10	0.16	5918	16.00	63,145	13.09	20.60	40.98	4,340,118	28.30	30.30	64.20	13.00	2.10	33.10	0.60	4.90
Italy	10.70	59.28	91.85	0.19	5832	54.00	376,719	6.24	24.90	36.65	58,223,744	31.20	12.00	61.60	16.70	1.40	33.80	5.40	0.00

(*continued on next page*)

Table A3 (*continued*)

	warm_up	trans	gdp_index	elprice	bovine	waste	ghg	ghg_pc	pov	emp	Pop	gini	educ	health	hous_costs	rooms	cities	overcrow	child
Latvia	6.00	15.74	100.00	0.11	378	58.00	4859	2.19	26.00	40.12	1,919,968	34.50	18.50	51.40	18.00	1.00	42.50	15.80	12.60
Lithuania	22.40	46.45	98.40	0.14	630	96.00	10,325	3.38	24.80	39.71	2,794,184	32.00	23.70	55.70	15.60	1.00	41.70	3.70	12.90
Luxembourg	0.30	76.60	95.40	0.13	188	20.00	9575	16.21	15.50	41.84	476,187	27.20	22.70	59.20	13.60	2.00	13.00	9.10	8.70
Netherlands	1.30	72.00	98.70	0.12	3690	63.00	185,262	10.72	14.90	48.94	16,357,992	25.10	25.50	59.10	28.00	1.80	45.10	3.00	4.80
Poland	3.20	67.80	90.00	0.19	5406	168.00	355,104	9.34	17.30	39.97	37,967,209	27.20	15.70	59.50	21.10	1.00	32.50	20.00	38.70
Portugal	17.50	32.04	93.45	0.18	1447	64.00	54,039	5.21	19.80	42.24	10,276,617	31.20	12.00	56.50	14.30	1.50	43.10	0.90	6.10
Romania	9.30	49.94	100.00	0.20	1911	127.00	82,765	4.21	30.40	42.22	19,414,458	33.10	9.90	57.40	0.00	0.90	28.80	7.50	22.80
Slovakia	3.60	65.31	95.20	0.19	432	86.00	33,651	6.17	14.80	42.94	5,373,180	20.90	11.90	52.20	18.10	1.10	20.80	16.70	13.20
Slovenia	2.30	50.00	97.19	0.14	460	73.00	11,846	5.75	14.40	44.00	2,010,269	22.70	18.50	53.90	13.10	1.10	17.80	7.40	4.20
Spain	5.90	57.56	94.87	0.16	5802	58.00	276,952	5.90	23.30	36.68	44,784,666	31.90	26.80	62.70	16.30	1.90	49.60	0.90	1.70
Sweden	0.90	0	94.30	0.13	1391	46.00	14,143	1.42	13.90	48.43	9,113,257	23.40	26.40	51.40	21.20	1.80	20.20	17.00	2.50
United Kingdom	4.50	75.33	98.30	0.13	9459	55.00	455,123	6.83	22.00	46.46	61,073,279	30.20	28.70	61.20	19.80	1.90	55.90	0.50	7.00

Table A4
Descriptive statistics: variables' maximum values (2007–2020).

	warm_up	trans	gdp_index	elprice	bovine	waste	ghg	ghg_pc	pov	emp	Pop	gini	educ	health	hous_costs	rooms	cities	overcrow	child
Austria	3.90	43.71	114.35	0.19	2026	79.00	82,431	10.22	20.60	49.16	8,858,775	28.30	31.30	61.40	19.20	1.80	36.60	14.50	30.00
Belgium	14.60	93.72	114.18	0.26	2573	109.00	137,261	13.28	21.60	42.18	11,455,519	27.50	37.60	64.60	23.10	2.30	54.30	5.50	3.10
Bulgaria	67.40	81.80	120.84	0.20	611	473.00	55,093	7.52	60.70	46.19	7,572,673	40.80	25.60	70.40	29.70	1.30	45.30	19.80	46.00
Croatia	10.20	56.03	113.32	0.21	467	102.00	24,689	5.73	32.60	41.20	4,313,530	31.60	22.00	63.10	25.30	1.20	32.20	17.40	60.00
Czechia	6.70	84.21	124.70	0.26	1373	88.00	147,313	14.24	15.80	49.89	10,649,800	25.30	22.10	64.10	25.20	1.60	35.50	23.50	36.00
Denmark	10.30	64.51	117.87	0.23	1630	44.00	74,982	14.54	18.30	51.47	5,806,081	27.80	33.70	67.50	33.70	2.10	37.60	11.20	16.00
Estonia	4.20	65.72	139.43	0.19	265	772.00	19,843	14.83	26.00	49.98	1,342,920	35.60	37.10	57.60	19.10	1.70	61.00	30.60	14.00
Finland	2.00	40.88	109.03	0.14	909	139.00	62,567	11.80	17.90	47.75	5,517,919	26.50	39.80	59.10	18.30	2.10	39.50	18.90	24.00
France	6.60	81.15	112.91	0.18	20,028	49.00	485,145	7.77	19.30	40.51	67,012,883	30.80	35.30	64.60	19.10	2.00	47.60	14.60	8.00
Germany	9.00	79.92	116.59	0.29	12,988	56.00	974,515	12.10	24.00	51.07	83,019,213	31.10	27.20	66.40	33.40	2.00	50.70	12.80	52.40
Greece	32.90	83.63	110.90	0.21	685	123.00	133,686	12.09	36.00	41.68	11,123,392	34.50	28.50	66.90	42.50	1.30	47.80	15.00	44.50
Hungary	15.00	82.87	129.91	0.27	933	154.00	69,680	7.14	34.80	46.17	10,066,158	28.70	23.60	62.50	26.70	1.60	32.80	19.20	26.00
Ireland	10.00	93.01	187.41	0.22	6674	74.00	74,215	17.52	30.90	51.18	4,904,240	31.30	42.80	69.60	18.60	2.40	36.00	2.40	18.20
Italy	21.30	80.39	105.10	0.24	6577	69.00	559,791	9.54	30.00	39.37	60,795,612	33.40	17.90	68.30	20.90	1.50	44.10	9.80	14.10
Latvia	22.50	40.77	133.62	0.24	422	97.00	12,149	6.12	40.10	48.13	2,208,840	37.50	33.20	56.80	22.40	1.30	47.10	41.80	43.00
Lithuania	36.20	67.04	140.04	0.23	788	198.00	19,316	6.01	34.00	49.33	3,249,983	37.90	38.70	59.80	21.80	1.60	43.50	25.90	45.00
Luxembourg	3.60	94.55	124.63	0.16	202	38.00	12,058	25.86	20.90	47.63	613,894	32.30	41.00	66.50	14.20	2.20	46.40	13.40	34.00
Netherlands	3.00	93.40	113.92	0.18	4315	68.00	217,152	13.04	17.00	51.97	17,282,163	28.20	36.60	65.20	31.20	1.90	66.10	7.20	15.30
Poland	22.70	86.19	138.01	0.26	6279	201.00	382,792	10.04	34.40	43.41	38,135,876	32.20	28.90	62.90	24.20	1.20	40.10	27.70	69.00
Portugal	41.90	56.19	106.92	0.30	1691	145.00	81,167	7.89	27.50	48.48	10,573,479	36.80	25.40	63.60	19.30	1.70	45.30	2.90	26.00
Romania	33.30	63.61	140.78	0.28	2819	416.00	120,817	5.85	47.00	45.40	21,130,503	38.30	16.20	61.50	28.40	1.10	37.70	12.80	59.00
Slovakia	7.80	84.55	126.52	0.25	502	167.00	41,814	7.77	21.40	47.40	5,450,421	26.10	23.90	56.70	27.40	1.20	26.90	24.70	40.00
Slovenia	6.10	62.71	119.05	0.21	489	114.00	18,621	9.01	20.40	49.55	2,080,908	25.00	31.50	65.10	17.10	1.60	19.60	27.70	16.00
Spain	11.10	80.67	110.64	0.26	6636	72.00	408,186	8.94	29.20	45.95	46,937,060	34.70	36.00	69.90	19.50	2.00	51.90	2.70	15.00
Sweden	2.70	13.55	121.21	0.17	1517	68.00	29,827	3.25	18.80	50.37	10,230,185	28.00	38.30	73.30	24.70	2.00	40.30	23.00	9.00
United Kingdom	10.60	96.53	117.41	0.19	10,075	81.00	674,148	11.24	24.80	49.06	66,647,112	33.90	40.60	65.60	28.90	2.30	75.90	7.70	33.00

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