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Assessment of energy poverty in EU countries in 2010-2022

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Abstract. The main goal of the paper was to analyze the level of energy poverty in EU countries, with particular emphasis on three years: 2010, 2015 and 2022. The basic definition of energy poverty assumes a situation in which a household is unable to provide for an adequate level of energy services at home. Choice of the time period for the analysis was dictated by the availability of statistical data and, on the other hand, by the desire to analyze the impact of the time factor on the phenomenon under study. The application of the modified TOPSIS method for the construction of synthetic measures, in which common coordinates of the Positive Ideal Solution and Negative Ideal Solution were calculated for all analyzed periods, made it possible to assess the dynamics of the analyzed phenomenon between these periods. The carried out analyses show that EU countries remain differentiated in terms of energy poverty levels, but that this variation has been decreasing over time. This clearly indicates that the level of the examined phenomenon is equalizing in the analyzed group of countries. Particularly important was the improvement in the positions of the member states, whose accession took place after 2004. An in-depth comparative analysis of changes in energy poverty levels between the "new" and "old" member states is the essential added value of this work. Due to the changing geopolitical conditions in Europe and around the world, it should be borne in mind that not only developing countries will face energy shortages. Therefore, the authors believe that it is crucial to commit to political actions and to conduct scientific

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research on the widest possible use of various types of energy in order to reduce energy poverty.

Keywords: energy poverty, analysis of dynamic, EU countries, TOPSIS method.

JEL Classification: C4, Q4

1. INTRODUCTION

The current socio-economic problems of the societies of European countries have deepened due to the emigration crisis, the SARS-COVID-19 virus pandemic, and the war in Ukraine. In this context, the stratification of societies and the increasing extent of poverty become significant problems. For instance, Eurostat (Eurostat, 2021a) estimates show that in 2020, 21.9% of the community's inhabitants were at risk of poverty and, despite a relatively high level of development, energy poverty is yet another challenge that Europe is facing.

Economic growth in recent centuries has made energy a structural necessity and a driving force for prosperity (Sovacool, 2011). Currently, the energy sector faces many difficulties resulting primarily from climate change, problems with the supply of raw materials, and the condition of infrastructure.

Energy poverty is a complex problem to which scientists and international organizations, including the United Nations (UN), the International Energy Agency (IEA), the International Atomic Energy Agency (IAEA) and the World Bank, devote much attention. Meanwhile, among the EU member states, only a few – Great Britain (until 2021), Ireland, France, Cyprus and Slovakia – have an official definition of energy poverty (Castaño-Rosa et al., 2019; Thomson & Snell, 2013). They are presented in Table 1.

Table 1

Definitions of energy poverty in selected countries

Country	Definition energy poverty
Great Britain	UK-wide (2001-2013), Northern Irland, Scotland, Wales (2013-): A household is said to be in fuel poverty if it needs to spend more than 10% its income on fuel maintain an adequate level of warmth England (2013-): A household is considered to be fuel poor where: they have required fuel costs that are above average (the national median level), were they to spend that amount, they would be left with a residual income below the official poverty line" (60% median income)
France	A person is considered fuel poor "if he/she encounters particular difficulties in his/her accommodation in terms of energy supply related to the satisfaction of elementary needs, this being due to the inadequacy of financial resources or housing conditions"
Ireland	the inability to afford adequate warmth in a home, or the inability to achieve adequate warmth because of the energy inefficiency of the home
Slovakia	"Energy poverty under the law No. 250/2012 Col/. Of Laws is a status when average monthly expenditures of household on consumption of electricity, gas, heating and hot water production represent a substantial share of average monthly income of the household"

Cyprus	The situation of customers who may be in a difficult position because of their low income as indicated by their tax statements in conjunction with their professional status, marital status and specific health conditions and therefore, are unable to respond to the costs for the reasonable needs of the supply of electricity, as these costs represent a significant proportion of their disposable income

Source: Barrett et al., 2022; Castaño-Rosa et al., 2019; Kerr et al., 2019; Thomson et al., 2016

In other countries of the world, the awareness of this issue varies. For example, the United States has not formally recognized it as distinct from general poverty at the federal level (Bednar & Reames, 2020). This limits effective response and prevention of this phenomenon.

In this context, an important aspect becomes the measurement of this phenomenon, as well as an attempt to answer the question about the nature of its changes over time. The main purpose of this work is to analyse the level of energy poverty and its dynamics in EU countries in the years 2010, 2015 and 2022. This was dictated by the availability of statistical data and, on the other hand, by the desire to analyze the impact of the time factor on the phenomenon under study. The choice of the year 2015 is particularly important due to the fact that since that year the energy transformation in the EU countries has accelerated, which resulted in, among others, increasing the dynamics of the share of energy from renewable sources in final energy consumption from 3.42 pp in 2010-2015 to 4.22 pp in the years 2015-2020 (Eurostat, 2024b), while reducing CO_2 emissions in both periods amounting to 9.5% and 16.7%, respectively (Eurostat, 2023a). Basing the study on three periods made it possible to analyze the impact of the time factor on the level of energy poverty, which is an important novelty in the literature on the subject. The undeniable added value of the work is also the in-depth analysis of changes in the values of diagnostic features, which makes it possible to indicate the causes of changes in the level of the analyzed phenomenon. The presented results will also fill the research gap regarding the differences between the countries of the "old" and "new" Union, i.e. before and after the accession in 2004, and also indirectly answer the question about the impact of the integration process.

In order to take into account the complex nature of the phenomenon of energy poverty, 11 selected indicators for 27 EU countries were used to describe it, characterizing such aspects as: the level of social assistance, housing costs, the wealth of societies, energy intensity of households, the level of energy prices and their dynamics. The Eurostat database was used as the main data source. The multidimensional nature of the studied phenomenon forced the use of multivariate statistical analysis methods for its analysis. These methods are applicable to phenomena that, due to their heterogeneous nature, must be considered on many levels (dimensions). Taking into account the assumed goal of the work, it was decided to use the TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution), which enables the classification of multi-featured objects. The modification of this method used in this work enabled not only the construction of synthetic measures indicating the level of energy poverty in individual EU countries, but also a comparative analysis of their levels between individual analysis periods. At the same time, unlike other measures used in the analysis of the phenomenon of energy poverty (see more: Sokołowski et al., 2019), it allows the use of a wider range of indicators, not limited only to the cost and income sphere. The calculations used proprietary algorithms for the R environment and the Statistica 13.3 package.

The work is divided into six main parts. In the introduction (part 1) the main aim of the work is presented. The second part, "Energy poverty – literature review", contains a review of the literature on energy poverty, both in terms of: theoretical, legal and state of the art for selected regions and countries of the world. The section "Materials and methods" discusses the statistical data used in the work and describes the research procedure. Section 4 consists of a presentation and synthetic analysis of the obtained results, which were referred to in the form of a discussion in Section 5. The work ends with a summary.

2. ENERGY POVERTY – LITERATURE REVIEW

2.1. Definitions of energy poverty

The basic definition of energy poverty assumes a situation in which a household is unable to provide an adequate level of energy services at home (Bouzarovski et al., 2021; Bouzarovski & Thomson, 2020). A similar definition of energy poverty was developed as part of the European Fuel Poverty and Energy Efficiency project, where it was defined as a phenomenon consisting in experiencing difficulties in maintaining an adequate standard of heat in the place of residence for a reasonable price (EPEE, 2009). The citizen's right to an appropriate temperature in the place of residence is enshrined in the Sustainable Development Goals of the United Nations (UN, 2015). In turn, energy poverty in the UK is currently defined as a situation where a household spends more than 10% of its total income on energy sources used to heat homes to an acceptable level (Bouzarovski, 2014).

Thus, the main approaches to the definition of energy poverty are structured as follows (Streimikiene et al., 2020):

- the amount of energy that is necessary to meet the necessary energy needs of households, such as: heating; lighting; cooking, etc.;
- a certain share of energy expenditure in total household expenditure;
- the amount of energy or specific type of energy carrier that are used by households on the poverty threshold;
- a certain level of income below which energy consumption and/or energy expenditure is presumed to remain unchanged, indicating that a minimum level of energy consumption has been reached.

While energy poverty is difficult to separate from the broader, more complex problem of poverty in general, access to energy infrastructure would avoid its most serious consequences and encourage development. According to the data of the International Energy Agency from 2015, the cost of ensuring universal access to energy by 2030 would require annual investments of USD 35 billion, which is only much less than the amount provided annually in fossil fuel subsidies (González-Eguino, 2015).

The problem of energy poverty is also one of the topics of the "Third Energy Package" and other documents of the European Union (Bouzarovski & Petrova, 2015). At the same time, this organization has attempted to control and reduce the impact of this negative phenomenon, including by creating the European Energy Poverty Observatory (EPOV), which creates a common space for debate on the problem of energy poverty in the European Union (Dhéret & Giuli, 2017; Kyprianou et al., 2019).

At the same time, several EU institutions, including the European Parliament, the European Economic and Social Committee and the Committee of the Regions, have put emphasis on harmonizing energy poverty statistics and estimates. Despite the general resistance to establishing a definition of energy poverty at the EU level, the European Commission suggested that energy poverty should be measured using the following indicators developed by Eurostat: Income and Living Conditions, Household Budget, Eurobarometer, European Quality of Life. Their proper selection is, in this case, an important matter (Thomson, Bouzarovski, et al., 2017).

2.2. Energy poverty in the World

In the research results published so far, there are significant differences in the causes of energy poverty between developed and developing countries (see (Bienvenido-Huertas et al., 2022; Cadaval et al., 2022; Gouveia et al., 2019; Lis et al., 2016; Lowans et al., 2021; Ntaintasis et al., 2019; Nussbaumer et al., 2012; Pachauri & Spreng, 2011; Salman et al., 2022; Thomson, Bouzarovski, et al., 2017; Thomson, Snell, et al., 2017)). In the first group of countries, due to the greater range of infrastructure and access to modern energy sources, it is related to the issues of affordability and energy efficiency. In developing countries, in turn, apart from the issue of costs, infrastructural problems related to the lack of access to energy sources, which are necessary to meet the needs of the inhabitants, are also becoming important factors (Aristondo & Onaindia, 2018; Sy & Mokaddem, 2022).

An estimated 50 million people in Europe live in energy poverty. In the United States, 33% of households experience energy poverty, while in Australia it is about 25% (Waddams Price et al., 2012). Research results indicate that Africa, South Asia and Central Asia remained among the energy poor regions (Boguszewski & Herudziński, 2018). Fig. 1 shows the multidimensional energy poverty index in the years 2001-2017 for selected countries in Africa, America and Asia.

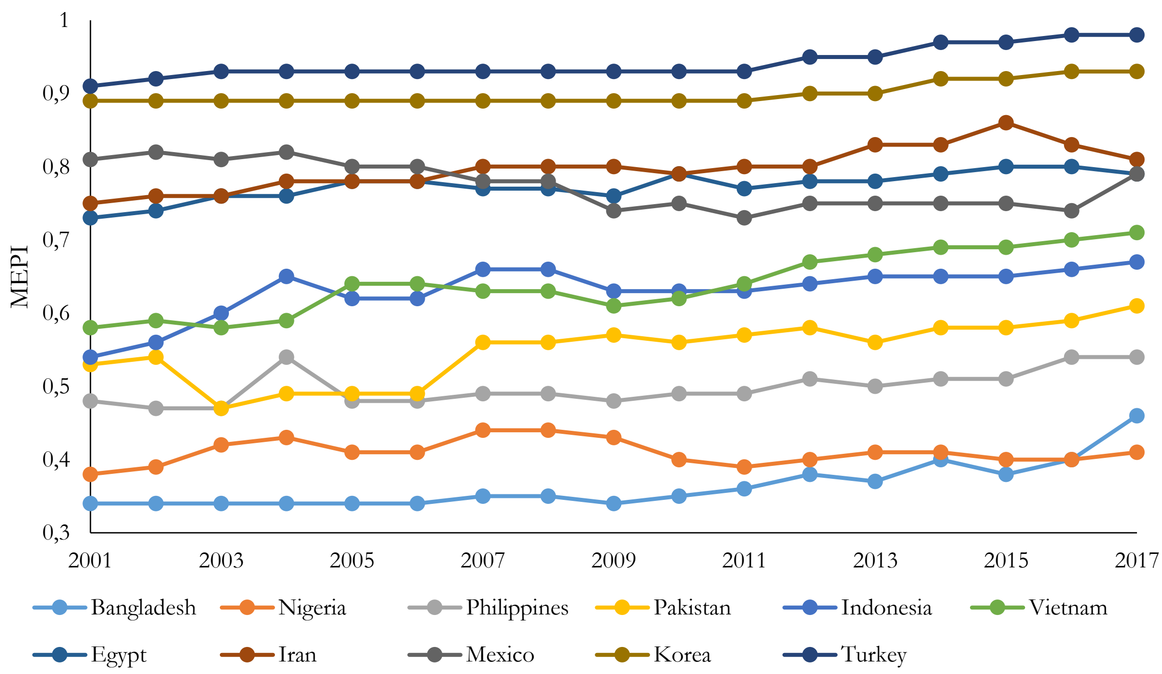

Figure 1. Multidimensional Energy Poverty Index Score in selected countries of Africa, America and Asia in years 2001-2017

Source: Rao et al., 2022

In the case of the "Old Continent", an increase in social awareness related to the energy transformation is noticeable (Campos and Marín-González 2020). The problem of energy deprivation is a particular threat to citizens of Eastern, Central and Southern European countries (Bouzarovski, 2014). In this context, they are particularly associated with the problem of energy degradation related to the poor condition of housing resources, the inability to change energy suppliers or the inability to regulate energy consumption (Bouzarovski, 2014; Herrero & Ürge-Vorsatz, 2010; Qin et al., 2022). Fig. 2 presents information on the share of households in 27 EU countries, that cannot provide an adequate level of heat in their homes.

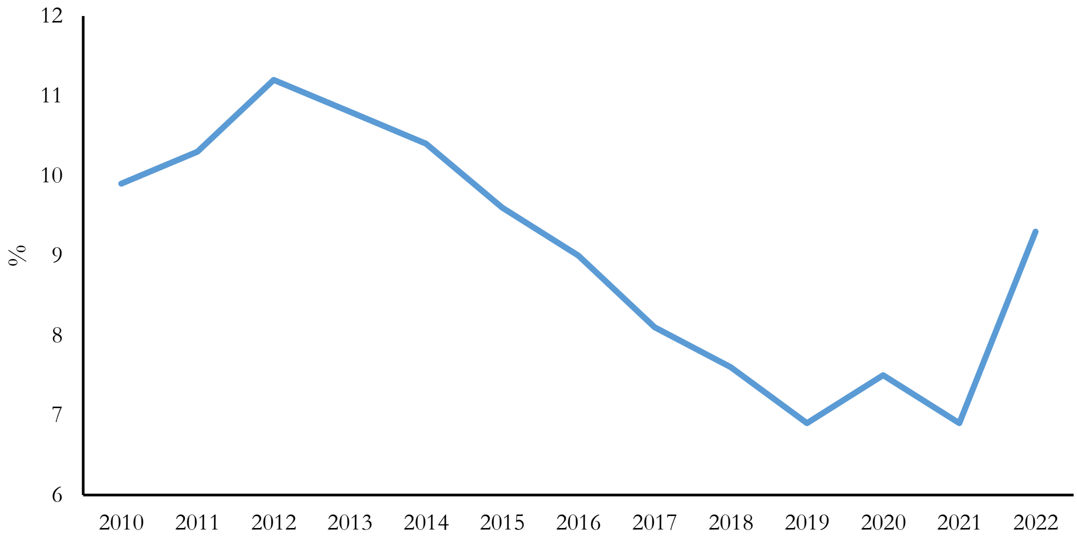

Fig. 2. Percentage of EU-27 households incapable to keep home adequately warm in years 2010-2022

Source: Eurostat, 2024a

In turn, access to renewable energy sources is often difficult due to costs and conditions: cultural, legal, geographical and infrastructural (Kariuki, n.d.). It should also be noted that, particularly in Eastern Europe, energy prices are rising faster than the incomes of the poorest households, with the consequent higher risk of energy vulnerability and energy poverty (Streimikiene et al., 2020). According to Eurostat data for 2012, 46.5% of the Bulgarian population are unable to keep their homes adequately warm during the winter, compared to only 4.2% in Estonia, 2.6% in Denmark and 2.6% in Sweden 1.4%. In 2020, these values were for: Bulgaria 27.5%, Estonia 2.7%, Denmark 3% and Sweden 2.7% (Eurostat, 2021b).

On the other hand, studies conducted in Australia (Churchill et al., 2022) allowed us to look at energy poverty and climate change from a different perspective. Results indicate that climate change, including global warming, can benefit a large country with a relatively mild climate, resulting in a small decrease in energy poverty in the short, medium and long term.

3. MATERIALS AND METHODS

3.1. Statistic data

As can be seen in the definition of energy poverty (section 2.1), it is multidimensional. In such a case, the basic research problem is the selection of a set of diagnostic features that should describe the studied phenomenon as much as possible. When constructing such a set, the issue of the availability of static data must also be taken into account, and in the case of analyzes covering several periods, also their comparability in time and space. The selection of the set of diagnostic features was based on research conducted by other authors, including: (Berti et al., 2023; Biernat-Jarka et al., 2021; Kashour & Jaber, 2024; Li et al., 2023; Thema & Vondung, 2020) and attempts were made to follow the methodological guidelines contained in the works (Energy Poverty Advisory Hub, 2023; Menyhért, 2023; Siksnelyte-Butkiene et al., 2021; Thomson, Bouzarovski, et al., 2017). At the same time, we wanted to include, apart from income and cost factors, also other aspects of this phenomena. Ultimately, eleven diagnostic features were qualified for the study:

- X_1 – housing cost overburden rate (%);
- X_2 – net social protection benefits related to the costs of housing (% of GDP);

- X_3 – inability to keep home adequately warm (%);
- X_4 – real expenditure per capita (PPS_EU27_2020);
- X_5 – share of housing and energy costs in household expenses (%);
- X_6 – cooling degree days (CDD)[1];
- X_7 – heating degree days (HDD)[2];
- X_8 – share of energy from renewable sources and biofuels in the final consumption of households (%);
- X_9 – final energy consumption in households per capita (GJ per capita);
- X_{10} – average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (%);
- X_{11} – average annual electricity price for households consuming between 2500-5000 kWh (PPS/kWh).

The construction of the above set is not accidental. The first three features are related to the level of social protection and the cost of living in individual countries. The next two refer to the wealth of societies. Features X_6 – X_9 describe the energy intensity of households. The last two, on the other hand, indicate the level of energy prices and their changes in individual countries. Among the analysed features, three should be considered stimulants (X_4, X_8 and X_9) and 8 destimulants.

The choice of three research periods resulted from several reasons. Firstly, the availability of statistical data turned out to be an important aspect. It was also one of the reasons for limiting the set of diagnostic features to only eleven. Secondly, the broad ten-year research horizon made it possible to analyse changes in housing costs, including those, directly related to energy poverty at the level of individual member states. Thirdly, the choice of 2015 was not accidental, as it was from that year that the energy transformation process accelerated significantly. This was mainly due to:

- signing the Paris Agreement (UNFCCC, 2022) in December 2015, the main goal of which is to limit the average increase in temperature on Earth,
- the approaching deadline (end of 2020) by which individual EU countries should achieve the targets set in Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 (EU, 2009) on the promotion of the use of energy from renewable sources .

3.2 TOPSIS method

To assess the level of energy poverty in EU countries in 2010, 2015 and 2022 the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method was used. It has been successfully used for many years for the statistical classification of multi-feature objects (Bąk et al., 2022; Balcerzak & Pietrzak, 2014; Chatterjee & Lim, 2022; Dmytrów, 2018; Gostkowski et al., 2019; Hezer et al., 2021; Roszko-Wójtowicz & Grzelak, 2019). Its main idea is based on determining the distance of a given object, characterised by a certain set of diagnostic features, from a certain pattern and anti-pattern (Hwang & Yoon, 1981). Due to the fact that these distances are determined on the basis of a set of features and not a single value, the impact of specific features on the value of the synthetic measure is eliminated in this way. The object with the smallest distance from the pattern and the greatest distance from the anti-pattern is considered optimal in this case.

The calculation procedure of the TOPSIS method consists of six steps:

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[1] a weather-based index to describe the energy needs to cool buildings.
[2] a weather-based index to describe the heating energy needs of buildings

1. Determination of weights for individual diagnostic features according to the following condition:

$$\sum_{k=1}^{j} w_k = 1 \tag{1}$$

To take into account the impact of a different number of diagnostic features in individual categories of the set of features, it was decided to use weights, which unit values were presented in Table 2 (Olson, 2004).

Table 2

Unit weights by category of diagnostic features

Category	Social situation	Wealth	Energy intensity	Energy cost
Features	X_1, X_2, X_3	X_4, X_5	X_6, X_7, X_8, X_9	X_{10}, X_{11}
Unit weights	$\frac{1}{12}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{8}$

Source: Authors' results

2. Making a set of diagnostic features comparable.

In order to make the set of diagnostic features comparable, the standardisation method was used (see also: (M. T. Lakshmi & Venkatesan, 2014; T. M. Lakshmi et al., 2019)), according to the following formula:

$$z_{ik,t} = w_k \cdot \frac{x_{ik,t} - \bar{x}_{k,t}}{S(x_{k,t})} \tag{2}$$

where:

- w_k – weight assigned to the k-th feature,
- $\bar{x}_{k,t}$ – arithmetic mean of *k*–th characteristic in year t,
- $S(x_{k,t})$ – standard deviation of *k*–th characteristic in year t.

3. Calculation of pattern and antipattern coordinates. Unlike the classical TOPSIS method, their coordinates were common for all analysed periods (see (Oesterreich et al., 2020; Walesiak & Obrębalski, 2017)):

$$z_{k,t}^{+} = \begin{cases} \max\limits_{i,t} z_{ik,t} & \text{for stimulants} \\ \min\limits_{i,t} z_{ik,t} & \text{for destimulats} \end{cases} \tag{3}$$

$$z_{k,t}^{-} = \begin{cases} \min\limits_{i,t} z_{ik,t} & \text{for stimulants} \\ \max\limits_{i,t} z_{ik,t} & \text{for destimulats} \end{cases} \tag{4}$$

where:

z_k^+ – *k*-th coordinate of Positive Ideal Solution,

z_k^- – *k*-th coordinate of Negative Ideal Solution.

4. Determination of the distance of the analysed objects (EU countries) from the pattern (Positive Ideal Solution) and anti-pattern (Negative Ideal Solution), in each of the periods. The Euclidean distance was used as a measure of distance.

$$d_{i,t}^{+} = \sqrt{\sum_{k=1}^{j} \left(z_{ik,t} - z_k^{*+}\right)^2} \tag{5}$$

$$d_{i,t}^{-} = \sqrt{\sum_{k=1}^{j} \left(z_{ik,t} - z_k^{*-}\right)^2} \tag{6}$$

where:

$d_{i,t}^{+}$ – Euclidean distance between *i*-th country and Positive Ideal Solution in year *t*,

$d_{i,t}^{-}$ – Euclidean distance between *i*-th country and Negative Ideal Solution in year *t*.

5. Calculation of the value of the synthetic measure ($Z_{i,t}$) for individual objects and periods, based on the distance from the pattern and anti-pattern:

$$Z_{i,t} = \frac{d_{i,t}^{-}}{d_{i,t}^{-} + d_{i,t}^{+}} \tag{7}$$

6. Construction of typological groups containing, for each of the analysed periods, objects similar in terms of the level of the synthetic measure:

$$\text{group 1: } \overline{Z_{\iota,t}} + S_{Z_{i,t}} \leq Z_{i,t} \tag{8}$$

$$\text{group 2: } \overline{Z_{\iota,t}} \leq Z_{i,t} < \overline{Z_{\iota,t}} + S_{Z_{i,t}} \tag{9}$$

$$\text{group 3: } \overline{Z_{\iota,t}} - S_{Z_{i,t}} \leq Z_{i,t} < \overline{Z_{\iota,t}} \tag{10}$$

$$\text{group 3: } Z_{i,t} < \overline{Z_{\iota,t}} - S_{Z_{i,t}} \tag{11}$$

4. RESULTS

Table 3 presents the values of synthetic measures, ranks and typological groups for the years 2010, 2015 and 2022. These measures were used to assess the burden of energy poverty in EU countries, and the higher the level of the synthetic measure, the lower the level of the analysed phenomenon.

Table 3

Values of synthetic measures, ranks and typological groups by years and countries

Country	$Z_{i,2010}$	ranks 2010	groups 2010	$Z_{i,2015}$	ranks 2015	groups 2015	$Z_{i,2022}$	ranks 2022	groups 2022
Belgium	0,543	9	2	0,548	10	2	0,453	24	4
Bulgaria	0,498	17	3	0,419	27	4	0,511	15	3
Czechia	0,498	18	3	0,462	22	3	0,529	11	2
Denmark	0,453	25	4	0,489	16	3	0,439	25	4
Germany	0,489	19	3	0,476	20	3	0,493	17	3
Estonia	0,556	6	2	0,577	4	2	0,481	21	3
Ireland	0,572	4	2	0,553	8	2	0,560	6	2
Greece	0,471	22	3	0,478	19	3	0,422	27	4
Spain	0,508	15	3	0,482	18	3	0,466	22	3
France	0,552	8	2	0,510	15	3	0,527	12	2
Croatia	0,539	13	2	0,538	12	2	0,603	3	1
Italy	0,569	5	2	0,484	17	3	0,433	26	4
Cyprus	0,429	26	4	0,601	3	1	0,503	16	3
Latvia	0,542	11	2	0,445	25	4	0,493	18	3
Lithuania	0,506	16	3	0,567	6	2	0,488	19	3
Luxembourg	0,677	1	1	0,701	1	1	0,663	1	1
Hungary	0,424	27	4	0,517	14	3	0,549	8	2
Malta	0,455	24	4	0,604	2	1	0,623	2	1
Netherlands	0,612	2	1	0,533	13	2	0,484	20	3
Austria	0,590	3	1	0,574	5	2	0,571	5	2
Poland	0,483	20	3	0,474	21	3	0,553	7	2
Portugal	0,536	14	2	0,459	23	3	0,546	9	2
Romania	0,459	23	4	0,432	26	4	0,461	23	3
Slovenia	0,541	12	2	0,556	7	2	0,600	4	1
Slovakia	0,479	21	3	0,455	24	4	0,516	14	3
Finland	0,556	7	2	0,539	11	2	0,525	13	2
Sweden	0,542	10	2	0,553	9	2	0,539	10	2

Source: Authors' results

For all analysed periods, the average values of synthetic measures were at a similar level. They were respectively: 0.521 (2010) and 0.520 (2015 and 2022). At the same time, the analysis of the values of the classical coefficient of variation shows that they were characterised by moderate variability: in the case of the first analysis period 10.87%, the second 11.98% and the third 11.22%. This indicates significant differences in the level of energy poverty in EU countries.

4.1. Energy poverty in 2010

For 2010, the highest level of the synthetic measure, i.e. the lowest level of burden of households with housing costs, was achieved by Luxemburg (0.677). This country was characterised by the lowest level of feature X_3 (inability to keep home adequately warm) and the highest level of the feature X_4 (real expenditure per capita) among all the analysed countries. At the same time, it stood out positively in terms of: final energy consumption in households per capita (X_9 – 2nd place), the level of electricity prices (X_{11} – 4th place) and a relatively low percentage of households overburdened by housing costs (X_1 – 6th place). The next places were taken by Netherlands (0.612) and Austria (0.590).

The lowest level of the measure was recorded for Hungary (0.424). This was mainly due to levels of features: X_1 (housing cost overburden rate) (21st place), X_2 (net social protection benefits related to the costs of housing) (22nd place), X_4 (real expenditure per capita) (20th), X_5 (share of housing and energy costs in household expenses) (20th) and X_{11} (average annual electricity price for households consuming between 2500-5000 kWh) (27th). This country ranked behind and Denmark (0.453) and Cyprus (0.429). Fig. 3 shows the spatial distribution of the countries in terms of the value of the synthetic measure for 2010 ($Z_{i,2010}$).

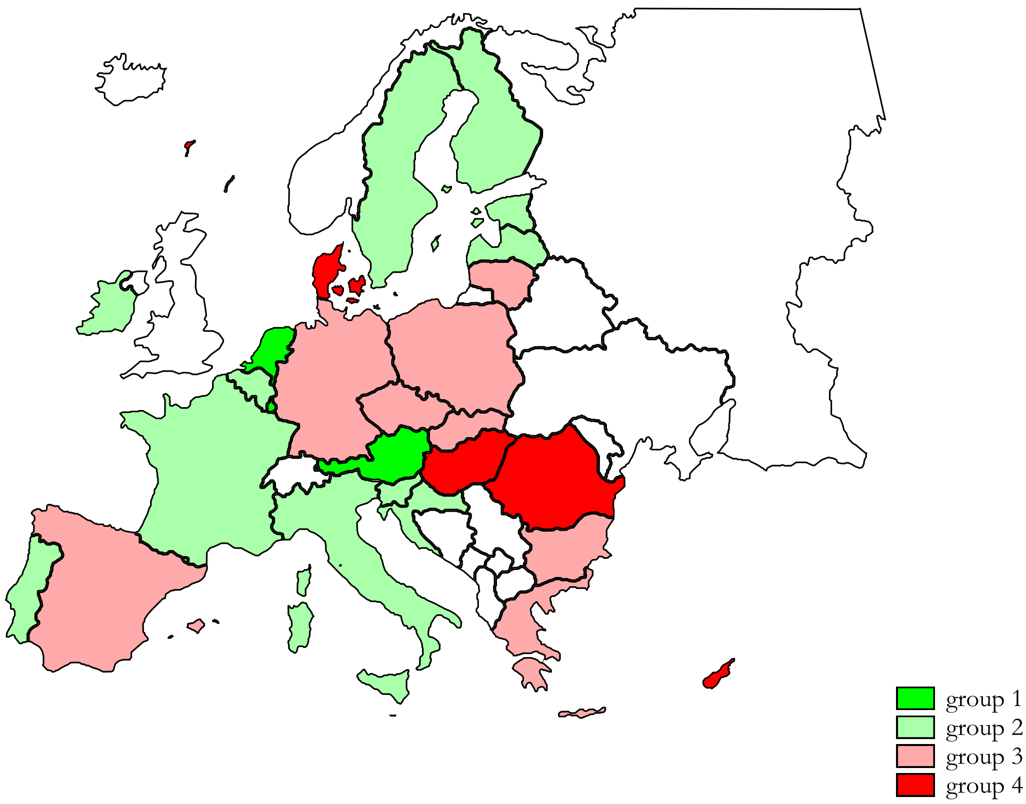

Figure 3. Spatial distribution of EU countries according to the value of the synthetic measure in 2010

Source: Authors' results

Moving on to the analysis of the average values of diagnostic features in 2010 and for individual typological groups (Table 4), it should be noted that for the countries of group 1, the most desirable values were achieved only for five features: inability to keep home adequately warm (X_3), real expenditure per capita (X_4), cooling degree days (X_6), final energy consumption in households per capita (X_9) and the average annual rate of change of the Harmonized Index of Consumer Prices for electricity, gas and other fuels (X_{10}). For group 2, these values were recorded for three characteristics: housing cost overburden rate (X_1), share of energy from renewable sources and biofuels in the final consumption of households (X_8) and the average annual electricity price for households consuming between 2500-5000 kWh (X_{10}). Group 3 was characterised by the most desirable values of net social protection benefits related to the costs of housing (X_2). The countries of group 4 were characterised by the least desirable values of six diagnostic features: housing cost overburden rate (X_1), expenditure on social protection related to covering the costs of housing (X_2), cooling degree days (X_6), final energy consumption in households per capita (X_9), the average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}) and the average annual electricity price for households consuming between 2500-5000 kWh (X_{11}).

Table 4

Average values of diagnostic features in 2010 by typological groups

	X_1 (%)	X_2 (% of GDP)	X_3 (%)	X_4 (PPS)	X_5 (%)	X_6 (CDD)	X_7 (HDD)	X_8 (%)	X_9 (GJ per capita)	X_{10} (%)	X_{11} (PPS/kWh)
2010	9.044	0.264	11.978	24633.3	22.196	123.913	3201.628	22.050	26.637	6.093	0.184
G1	8.733	0.193	2.200	44766.7	22.000	25.683	3520.683	11.857	36.000	0.500	0.160
G2	7.000	0.278	8.955	24045.5	21.936	72.971	3621.418	24.969	30.236	5.500	0.159
G3	10.650	0.144	18.000	19637.5	22.888	123.554	3144.349	21.535	21.588	4.275	0.201
G4	11.160	0.470	14.860	21840.0	21.780	295.498	2178.302	22.570	21.180	13.660	0.225

Source: Authors' results

4.2. Energy poverty in 2015

The analysis of the value of the synthetic measure for 2015 shows that its highest level was recorded for Luxemburg (0.701), which was characterised by the lowest level of the feature X_3 (inability to keep home adequately warm) (1st place), the highest level of the feature X_4 (real household expenditure per capita) (1st place) and was positively distinguished in terms of: final energy consumption in households per capita (X_9) (2nd place), average annual electricity price for households consuming between 2500-5000 kWh (X_{11}) (3rd place), average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}) (4th place) and the housing cost overburden rate (X_1) (6th place). The following positions in the classification were occupied by: Malta (0.604), Cyprus (0.601).

The lowest values of the taxonomic measure were recorded for Latvia (0.445), Romania (0.432) and Bulgaria (0.419). They also constituted the fourth typological group with Slovakia (0.455). Position of Bulgaria was mainly due to the values of the following features: housing cost overburden rate (X_1) (22nd), inability to keep home adequately warm (X_3) (27th), real household expenditure per capita (X_4) (27th place), cooling degree days (X_6) (20th), final energy consumption in households per capita (X_9) (25th place) and average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}) (27th place). Fig. 4 shows the spatial distribution of the countries in terms of the value of the synthetic measure for 2015 ($Z_{i,2015}$).

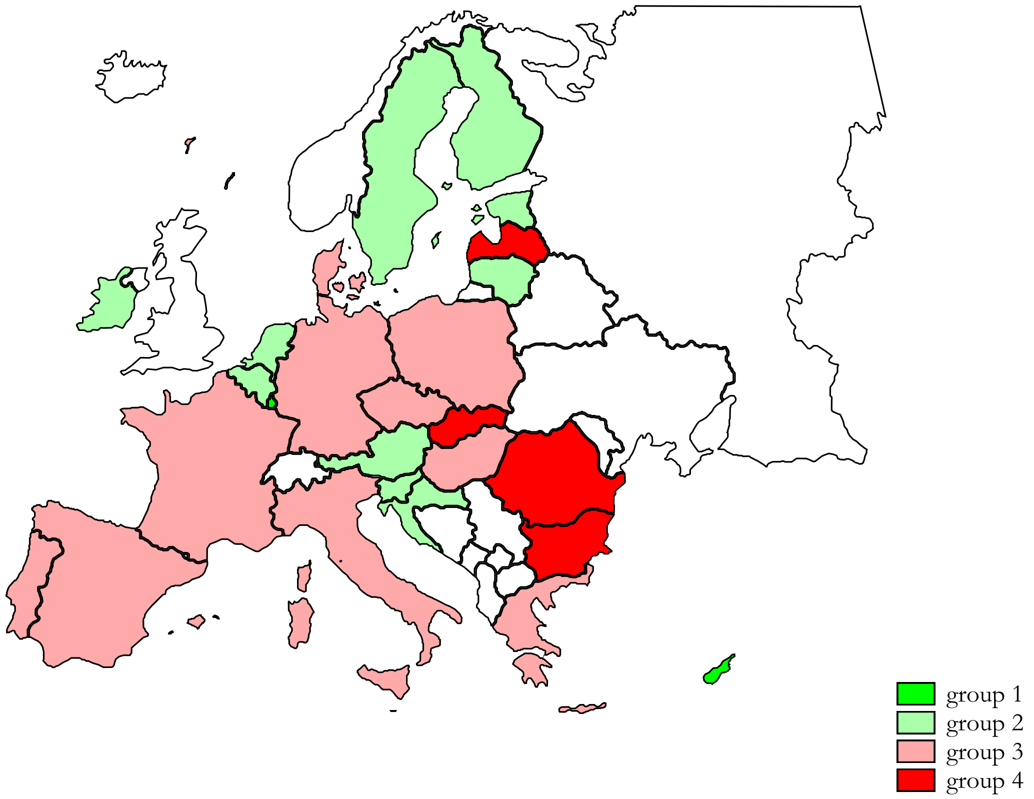

Figure 4. Spatial distribution of EU countries according to the value of the synthetic measure in 2015

Source: Authors' results

The analysis of the average values of diagnostic features for 2015 for individual typological groups (Table 5) shows that the most desirable values for 6 out of 11 features were recorded in group 1. A particularly large advantage over other groups was noted for: housing cost overburden rate (X_1), real expenditure per capita (X_4), heating degree days (X_7) and average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}).

In the case of the second group of countries, better average values were recorded for: inability to keep home adequately warm (X_3), cooling degree days (X_6) and final energy consumption in households per capita (X_9). As in 2010, the countries of group 4 stand out negatively against this comparison, for which the least desirable average values were recorded for four diagnostic features: inability to keep home adequately warm (X_3), real expenditure per capita (X_4), final energy consumption in households per capita (X_9), and average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}).

Table 5

Average values of diagnostic features in 2015 by typological groups

	X_1 (%)	X_2 (% of GDP)	X_3 (%)	X_4 (PPS)	X_5 (%)	X_6 (CDD)	X_7 (HDD)	X_8 (%)	X_9 (GJ per capita)	X_{10} (%)	X_{11} (PPS/kWh)
2015	10,170	0,238	11,222	27840,7	22,078	147,276	2696,851	24,518	23,167	-3,700	0,209
G1	3,667	0,217	14,433	42466,7	17,167	477,420	1381,373	11,780	20,067	-11,467	0,172
G2	7,820	0,275	7,120	30210,0	21,970	45,997	3364,499	25,687	27,450	-4,120	0,184
G3	13,750	0,287	11,590	25390,0	23,370	159,867	2315,138	23,126	22,330	-3,410	0,236
G4	11,975	0,038	18,150	17075,0	22,800	121,390	2968,625	34,630	16,875	2,450	0,233

Source: Authors' results

4.3. Energy poverty in 2022

In the last year of the analysis, the highest score for the synthetic measure was again recorded for Luxemburg (0.663). This fact was influenced by the values of real expenditure per capita (X_4) (1st place), net social protection benefits related to the costs of housing (X_3) (2nd place), final energy consumption in households per capita (X_9) (4th place) and the average annual electricity price for households consuming between 2500-5000 kWh (X_{11}) (4th place). To the first group, there also belonged: Malta (0.623), Croatia (0.603) and Slovenia (0.600).

The countries with the highest level of housing costs, and thus the highest risk of energy poverty (group 4) in 2022, include: Belgium (0.453), Denmark (0.439), Italy (0.433) and Greece (0.422). The position of the last country was mainly due to the value of five diagnostic features: housing cost overburden rate (X_1) (27th place), inability to keep home adequately warm (X_3) (25th place), real expenditure per capita (X_4) (26th place), cooling degree days (X_5) (23rd place), final energy consumption in households per capita (X_9) (23rd place). Fig. 5 shows the spatial distribution of the countries in terms of the value of the synthetic measure for 2022 ($Z_{i,2022}$).

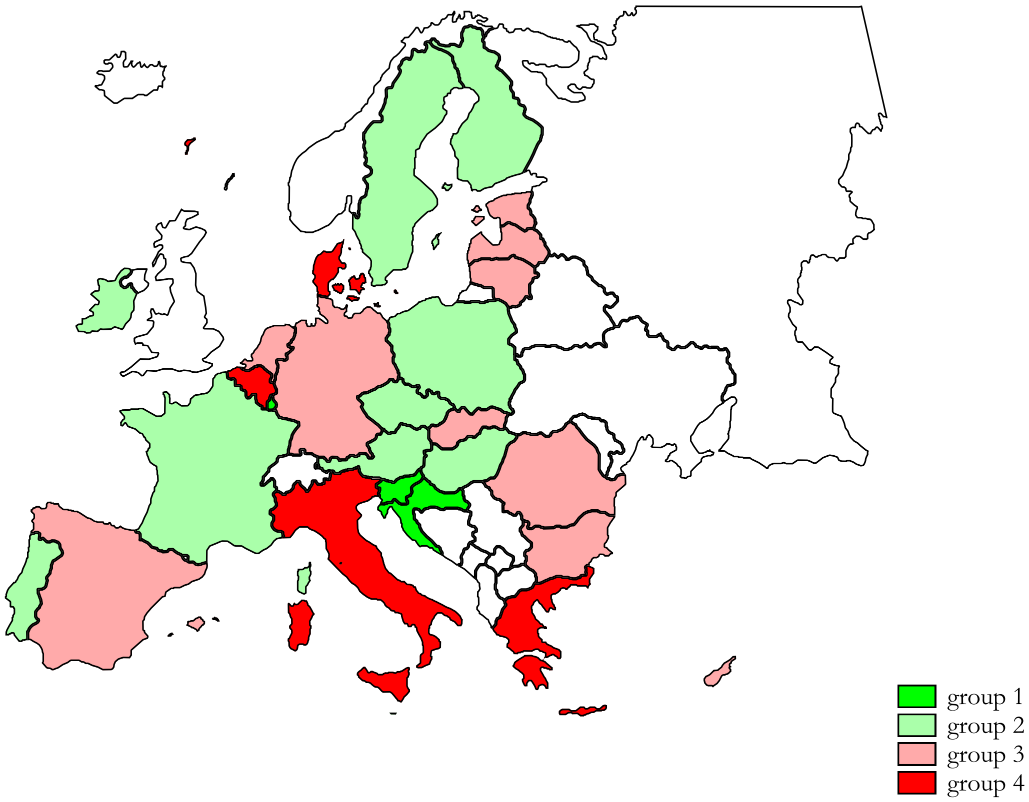

Figure 5. Spatial distribution of EU countries according to the value of the synthetic measure in 2022
Source: Authors' results

Analyses of the average values of diagnostic features for 2022 (Table 6), with particular emphasis on typological groups, indicate a significant advantage of countries of the 1st typological group.

Table 6

Average values of diagnostic features in 2022 by typological groups

	X_1 (%)	X_2 (% of GDP)	X_3 (%)	X_4 (PPS)	X_5 (%)	X_6 (CDD)	X_7 (HDD)	X_8 (%)	X_9 (GJ per capita)	X_{10} (%)	X_{11} (PPS/kWh)
2022	7,893	0,229	8,644	37277,8	22,211	155,829	2658,396	25,879	23,226	41,770	0,255
G1	6,500	0,058	4,825	46375,0	17,300	290,705	1993,378	26,668	20,775	17,375	0,180
G2	6,433	0,338	6,144	39922,2	24,222	74,240	3090,099	25,332	26,278	32,322	0,215
G3	7,350	0,176	12,110	31270,0	21,440	159,831	2732,385	27,888	20,950	51,020	0,287
G4	13,925	0,285	9,425	37250,0	24,525	194,520	2167,113	21,300	24,500	64,300	0,342

Source: Authors' results

Out of 11 diagnostic features constituting the basis for the construction of a synthetic measure, in 7 cases the desired values of diagnostic features were recorded for this group. A particularly advantage was observed in the case of: net social protection benefits related to the costs of housing (X_2), inability to keep home adequately warm (X_3), real expenditure per capita (X_4), share of housing and energy costs in household expenses (X_5), heating degree days (X_7) the average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}) and average annual electricity price for households consuming between 2500-5000 kWh (X_{11}). Comparing the information from tables 2, 3 and 4, it should also be noted that the predominance of group 1 increased in subsequent periods of the analysis. Only for housing cost overburden rate (X_1), cooling degree days (X_6) and final energy consumption in households per capita (X_9), more desirable values were recorded for group 2. At the same time, as for 2010 and 2015, the average values of diagnostic features for group 4, especially the housing cost overburden rate (X_1), share of housing and energy costs in household expenses (X_5), share of energy from renewable sources, biofuels in the final consumption of households (X_8) and average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}), were worse than for the other groups.

5. DISCUSSION

The analysis of the values of synthetic measures in the three analysed years shows that they differed in terms of the level of energy poverty. The lowest value of Pearson's linear correlation coefficient (0.316) between synthetic measures in the studied years was recorded between 2010 and 2022 (Table 7).

Table 7

Pearson's linear correlation coefficients between the values of synthetic measures for the years 2010, 2015 and 2022

	$Z_{i,2010}$	$Z_{i,2015}$	$Z_{i,2022}$
$Z_{i,2010}$	1,000	0,438*	0,316
$Z_{i,2015}$	0,438*	1,000	0,552*
$Z_{i,2022}$	0,316	0,552*	1,000

* statistically significant at α=0,05

Source: Authors' results

The reason for this can be seen in the low level of indicators characterising the "new" EU member states. It should be remembered that in 2004, the largest expansion in the history of this organisation took place, covering ten countries, including eight from the former Eastern Bloc, in January 2007 two more: Bulgaria and Romania, and finally Croatia in 2013. These countries clearly differed in terms of socio-economic development from their Western European members (ESPON, 2011). This had a direct impact on the financial opportunities for social assistance provided to citizens (ILO, 2010). Therefore, these countries were distinguished by low, compared to the others, values of: net social protection benefits related to the costs of housing (X_2) and real expenditure per capita (X_4), which resulted i.e. a high percentage of inhabitants could not afford a meal containing meat or vegetarian equivalent (Di Meglio, 2013). For this reason, they dominated typological groups 3 and 4.

Changes in the value of the synthetic measure in 2015 compared to 2010 resulted from several reasons. The purchasing power of the inhabitants of the "new" member states has clearly increased. Their real expenditure per capita (X_4) grew (on average) relatively almost twice as fast as in other EU countries – 18.2% vs. 9.9%, while in absolute terms it was still the "old" EU countries that had the advantage: 2869.23 vs. 3521.43 PPS (see: Eurostat, 2023b; IMF, 2010; Matkowski et al., 2016; Rapacki & Próchniak, 2008). In this context, the changes in the values of the housing cost overburden rate (X_1) and net social protection benefits related to the costs of housing (X_2) are interesting, which for "new" members amounted to: -0.1 p.p. and -0.05 p.p., while for the "old" ones: +2.3 p.p. and -0.004 p.p. This may have been caused by a significant increase in energy prices – in the case of average annual electricity price for households consuming between 2500-5000 kWh (X_{11}), the average relative increase in the second group of countries reached 23%, while for newly admitted 7.9% (see: Rademaekers et al., 2018). This resulted in an increase in the share of household costs of living in final consumption in the first group of countries by 0.9 p.p. on average and affected, at least in part, electricity consumption by households (X_8), which decreased compared to the base year by 9.1% for the "new" and 13.6% for the "old" member states respectively. Other factors affecting consumption during this period include actions taken by EU institutions promoting energy efficiency (e.g. withdrawal of incandescent light bulbs from 1 September 2012) and general technological progress. As a result of these factors, countries such as Malta, Cyprus and Hungary strengthened in the ranking for 2015 (Table 3), while the Netherlands, Portugal and Italy moved downwards. At the same time, the use of energy from renewable sources by households (X_7) increased, an average by 2.5 p.p across the EU, with the difference between the "old" and "new" EU members amounting to approx. 0.5 p.p. (respectively: 2.8 and 2.1 pp.). In the case of the first group of countries, this means that share increased by approx. 25.9% and was almost 2,5 times higher (10.3%) than in the group of "new" member states.

In 2022, compared to 2015, a further increase in real expenditure per capita is noticeable (X_4), on average by 28.1% (10014.29 PPS) among the "old" and 45.5% (8815,38.69 PPS) among the "new" member states (see: Eurostat, 2023b; IMF, 2010; Matkowski et al., 2016; Rapacki & Próchniak, 2008). This had a clear impact on the levels of housing cost overburden rate (X_1), which significantly decreased on average by 1.8 and 2.8 p.p. respectively. There was also a high increase of electricity prices, which for the surveyed group of consumers (X_{11}) amounted to approx. 21.5% on average. Among the "old" member states, there was a further reduction in final energy consumption in households per capita (X_9) by 2.2%, and for "new" a 5.2% increase was noted. The share of energy from renewable sources and biofuels in the final consumption of households continued to increase (X_8) – on average by 2.2 p.p. for the "old" EU countries and 0.5 p.p. among the "new" ones. Relatively, this percentage increased in both groups by 23,3% and 11.8% respectively, which at the same time indicates the rapid development of green energy sources in the EU countries (European Commission, 2022b; IRENA, 2018).

The analysis of the average values of diagnostic features in the analyzed periods (Table 4-6) indicates the lack of a high level of discrimination between typological groups of countries, especially for groups 1-3. This means that although group 1 included (theoretically) countries with the most desirable values of diagnostic features, based on the analysis of their average values, they did not always turn out to be the most optimal. This was particularly visible for 2010 (Table 4), and may result from disproportions related to socio-economic development, as well as access to energy carriers and their prices (level and stability) within countries belonging to particular groups, as well as their specific features. In the next two periods (2015 and 2022), these values are more ordered, i.e. the most desirable ones were most often for the countries of group 1 and the least desirable ones were for the countries of group 4. However, this does not mean that the disproportions between the countries have deepened, but rather that they have decreased within individual typological groups and the entire Community. This is an obvious result of the general policy pursued by the EU and aimed at deep integration of the member states (see: Crucitti et al., 2023; EC, 2020).

It is worth noting the results of the analysis of the interdependence of the values of diagnostic features in particular periods. While for the majority of diagnostic features the values of correlation coefficients are higher than 0.8, two significantly differ: average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}) and the average annual electricity price for households consuming between 2500-5000 kWh (X_{11}) (Table 8).

Table 8

Pearson's linear correlation coefficients between diagnostic features X_{10} and X_{11} in particular periods

	X_{10}: 2010	X_{10}: 2015	X_{10}: 2022	X_{11}: 2010	X_{11}: 2015	X_{11}: 2022
X_{10}: 2010	1,000	-0,635*	-0,366	-	-	-
X_{10}: 2015	-0,635*	1,000	-0,123	-	-	-
X_{10}: 2022	-0,366	-0,123	1,000	-	-	-
X_{11}: 2010	-	-	-	1,000	0,520*	0,188
X_{11}: 2015	-	-	-	0,520*	1,000	0,611*
X_{11}: 2022	-	-	-	0,188	0,611*	1,000

* statistically significant at $\alpha=0,05$

Source: Authors' results

The values of correlation coefficients for: average annual rate of change of the Harmonized Index of Consumer Prices (HICP) for electricity, gas and other fuels (X_{10}) and the average annual electricity price for households consuming between 2500-5000 kWh (X_{11}) clearly indicate differences in the dynamics and level of energy prices between particular periods. In the case of feature X_{10}, negative values indicate a reversal of the trend, i.e. countries that in 2010 were characterised by an increase in energy prices, in the remaining years covered by the study, recorded a decrease in their value. The values of the correlation coefficients for the X_{11} feature indicate significant changes in the levels of electricity prices for households in individual countries in 2015 and (especially) 2022 compared to 2010.

Due to the fact that the price of energy directly affects the level of its consumption, it also affects the level of energy poverty. The reasons for this could be the increase in the level of energy generation from renewable sources, which share in household consumption was increasing. The production of green energy becomes crucial due to its lower costs (Howell, 2022). In turn, reducing energy costs and facilitating access to it, is one of the ways to quickly reduce the level of energy poverty in the short term.

In the context of the possibility of production of green energy by individual member states, the attachment of some countries to the use of non-renewable energy sources and their dependence on sources of obtaining them should be considered negative (Anderson, 2008; Corbeau, 2022; European Commission, 2022a).

Therefore, the question should be asked: why, despite the improvement in the value of diagnostic features in almost all analysed areas, the values of the synthetic measure between 2010 and 2022 did not significantly improve? Looking at the average values, we can get such an impression, however, the analysis of the ranges and medians of measures in individual periods – 0.253 and 0,536 (2010); 0.282 and 0.517 (2015); 0.241 and 0,516 (2022) – indicates a slight improvement in the level of energy poverty in EU countries, through slow but noticeable reducing the differences between the "best" and "worst" countries, although the variation, measured by the classical coefficient of variation, is still relatively high and exceeds 11% in 2022.

It should also be emphasized that the results obtained in this study, despite different research methodology and differences in the set of diagnostic features, especially in terms of the spatial distribution of countries, are also confirmed in other publications. (Bouzarovski & Thomson, 2020) indicate that in 2018, the countries of Eastern, Central and Southern Europe, including Bulgaria and Greece, were the ones for which the highest levels of the analyzed phenomenon were recorded, including: in the context of the indicator twice the national median share on energy expenditure in income (2M). Despite a different methodology, similar results for the years 2014-2019 can also be found in work (Halkos & Gkampoura, 2021), and for 2020 in work (Kashour & Jaber, 2024). At the same time, the highest reductions in the level of energy poverty occurred, among others, Latvia and Italy. In the above works, the lowest levels of energy poverty were recorded for the Nordic countries - Norway and Sweden, supplemented by the Netherlands, Luxembourg and Denmark.

Similar conclusions come from the analyzes presented in this work. In the case of countries with the highest level of the analyzed phenomenon, i.e. countries of Eastern, Central and Southern Europe, were classified into typological groups 3 and 4. In the case of the above-mentioned Latvia, between 2015 and 2022 it advanced in the ranking by 7 places. In turn, referring to the countries with the lowest level of energy poverty: Sweden, the Netherlands and Luxembourg, in 2022 they took places 10, 20 and 1, respectively, and were classified into typological groups 1 and 2.

Significant differences are also visible. For example, in the works cited above: Germany, France, Austria and Belgium are countries with a low level of energy poverty. However, as the results of our research indicate, these countries are characterized by high levels of housing cost overburden rate (X_1), share of housing and energy costs in household expenses (X_5) as well as a high level of costs of energy (X_{10}, X_{11}) compared to other EU countries. These differences also indicate how difficult it is to assess the phenomenon of energy poverty, especially at the international level

SUMMARY

Analysing the results presented in this paper, especially for the "old" EU countries, the fact of low levels of synthetic measures may be puzzling. This situation may be due to several reasons. These countries have much more developed social programs and provide them with much larger funds. According to Eurostat data (Eurostat, 2023c) for years 2010-2021, share of expenditure on social protection in GDP was (on average) higher by 7.4 (2020) to 10.7 (2018) p.p. than in the countries admitted to the EU after 2004, with an average of 7.3 (2021) to 9.1 (2010) times higher GDP (World Bank, 2022). As a result, the costs incurred by the societies of the 14 countries of the "old" EU in terms of ensuring a high level of net social protection benefits related to the costs of housing (X_3) are higher than the others. At the same time, despite the high level of real expenditure per capita, these countries are characterised by a high level of living costs (NUMBEO, 2022), which results in a higher level of household overburden with housing costs (X_1). At the same time, due to different climatic and cultural conditions, a higher level of energy consumption was noted for all periods of the analysis, characterised in particular by the level of heating degree days (X_7) and final energy consumption in households (X_9). In the "old" EU countries the share of energy from renewable sources and biofuels in the final consumption of households was also low (X_8).

The research carried out in the work also shows that in the analysed research period there were clear changes in the values of synthetic measures, especially in the years 2010-2022. They mainly concerned countries that joined the EU after 2004, and for those values of synthetic measures, in most cases, improved. This resulted in shifts in the ranking compared to 2010. The above changes resulted primarily from the improvement in the economic situation of societies, characterised by real household expenses (X_4), which forced adjustments in the values of housing cost overburden rate (X_1) and net social protection benefits related to the costs of housing (X_2). There was also a noticeable reduction in the level of energy consumption described by the feature: X_6 (cooling degree days), X_7 (heating degree days), X_9 (final energy consumption in households). Surprisingly, the increase in the share of energy from renewable sources in the final consumption of households (X_8) did not reduce electricity prices (X_{11}). Despite this, the average value of synthetic measures in each of the periods did not change significantly.

To summarise, the research results presented in the paper are part of the debate on energy poverty, which is particularly important after Russia's aggression in Ukraine. Restrictions in the availability of energy carriers and their high prices have a negative impact on both the economies of the EU Community countries and their societies, exacerbating the problems of i.a. such as energy poverty. However, detailed analysis of this phenomenon will only be possible later, when the latest statistical data becomes available.

According to the authors, political actions as well as conducting scientific research on the widest possible use of various types of energy are important in reducing energy poverty (Al Kez et al., 2024; Carfora & Scandurra, 2024; Tundys & Bretyn, 2023; Zhao et al., 2022). Due to the changing geopolitical conditions in Europe and around the world, it should be borne in mind that not only developing countries will face energy shortages. The current political and economic situation shows that developing a single scenario for meeting energy needs has become insufficient. Hence, cooperation between countries regarding research and development of renewable energy (from various sources), promoting renewable energy technologies, actively participating in cooperation forums and using experience in this field from other countries becomes an important aspect. It is also important to provide legal support for the development of the renewable energy industry to provide it with a credible legal guarantee. Moreover, governments of all countries should prepare special funds for research and development of renewable energy technologies so as to be able to provide sufficient capital base for the development of the renewable energy industry.

The dynamically changing international situation affecting the prices of energy carriers, as well as the internal socio-economic problems of the entire Community and individual member states, including perturbations related to the introduction of the "European Green Deal" plan, make the forecast of the direction of changes in the level of such a complex phenomenon such as energy poverty, even in the short term may be subject to a very large error. However, the results of the research carried out in this study show that the differences between the new and old Member States should be expected to slowly fade away. This will be a consequence of socio-economic development, the development of new energy generation technologies, including from renewable sources, and activities under the EU Cohesion Policy.

The authors also point out the difficulties in selection indicators for the study that would ensure comparability of data for three selected periods and all countries. However, despite the limitation of the set of diagnostic features to eleven, an undeniable advantage of the work is the analysis of energy poverty and its changes over time, which makes it possible to detect the differences between the "new" and "old" EU countries.

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