



Multi-Criteria Assessment of the Effectiveness of the Implementation of Energy Policies in the European Union-27 Member States

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Abstract

Energy independence and climate neutrality are fundamental goals of European Union (EU) economic policy. Achieving these goals requires considerable determination from all member states and public consent to the changes being made. This paper addresses these pressing and extremely important issues. The aim of the research was to assess the effectiveness of the implementation of energy policies in the EU-27 countries. This assessment is crucial, as these policies and their outcomes are key to achieving both goals. To conduct this assessment, a research methodology based on a multidimensional approach to problem-solving under uncertain conditions was developed. The research employed a set of 13 selected indicators and multi-criteria decision making (MCDM) methods, including combinative distance-based assessment (CODAS), technique for order of preference by similarity to ideal solution (TOPSIS), and viekriterijumsko kompromisno rangiranje (VIKOR), as well as the Hurwicz criterion. To determine the weights of the indicators, methods such as criteria importance through inter-criteria correlation (CRITIC), statistical variance, equal weighting, and Laplace's criterion were used. Based on the determined values of the energy policy implementation efficiency index (IEEPI) for 2013-2022 for the countries studied, rankings were established. These rankings allowed for a comparison of the levels achieved by these countries in 2013 and 2022. The results indicated that Sweden and Finland achieved the best outcomes, while Ireland, Luxembourg, Malta, and Cyprus performed the weakest. Additionally, an assessment of the effectiveness of the implementation of the EU-27 energy policy was conducted based on the values of the indices of the dynamics of changes in the indicators, resulting in the IEEPI-DCI (dynamics of changes of indicators) index. This new approach provided an additional assessment of the changes that occurred in the EU countries over the study period relative to the base year. In this context, Malta and Estonia, as well as Slovenia and Hungary, showed the most progress, while Lithuania, Croatia, Denmark, and Austria showed the least. Both research approaches provided opportunities to assess the effectiveness of the implementation of energy policies in the EU-27 countries. These findings should inform the development of strategies for economic development, energy security, and independence. The current geopolitical situation in Europe and the challenges in implementing the European Green Deal highlight the need for a new approach to the EU's common climate and energy policy. The results of this research should contribute to discussions about its future directions.

Keywords: Energy policy; Energy neutrality; EU-27; Multi-criteria approach; Energy policy implementation efficiency index.

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1. Introduction

Global climate change is having an increasingly negative

impact on the environment and the well-being of society, including future generations.^[1-3] Greenhouse gas (GHG) emissions are the largest contributor and are primarily generated from the energy sector, resulting from the production and delivery of energy to end users.^[4] The main reason for this, despite growing public awareness, is the widespread use of electricity and heat produced from conventional resources such as oil, coal, and gas.^[5,6] This approach poses a major threat to the environment and, at a later stage, to the health and lives of citizens. The negative effects

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of using conventional energy resources are therefore forcing changes in the energy policies of many countries and regions. From a social and economic point of view, these measures also conflict with the concept of sustainable global economic development.^[7] A far better solution is to use renewable energy sources (RES) for energy production, which aligns well with the concept of sustainable development.^[8-10] This is because the production and consumption of energy from these sources do not emit greenhouse gases into the atmosphere. It also increases the energy independence of countries, especially those that do not have deposits of conventional energy resources.

Measures aimed at achieving climate neutrality and energy independence are being taken in many countries, including those in the European Union (EU). For many years, the EU has taken concrete initiatives and consistently applied strict policies aimed at reducing greenhouse gas emissions and increasing the share of RES in the energy mix.

Recent efforts include the adoption of the "Fit for 55" package, through which the EU pledges to reduce greenhouse gas emissions by at least 55% by 2030, relative to 1990 levels. In addition, the share of renewable energy in the energy mix of member countries is to increase to 40% by 2030. Another element of this process is the improvement of energy efficiency, which is targeted to increase by 32.5%. These and other measures aim to achieve climate neutrality and transform the EU into a modern, environmentally sustainable, and competitive economy.^[11] Achieving these goals requires individual EU member states to take actions that are appropriate to these objectives. Given the significant economic and social diversity among member states, achieving these goals is particularly challenging for some countries. To address this, the Just Transition Fund was introduced to support this group of member states.^[12] The idea of a just transition, strongly promoted in the EU, focuses mainly on minimizing the social impact of energy transition processes. The goals of building an environmentally sustainable economy and achieving energy independence are generally well understood and largely accepted by the public across EU member states. In particular, attaining energy independence has become an absolute priority of EU economic policy, especially in the context of the ongoing war in Ukraine.

It is also clear that the pursuit of climate neutrality and energy independence is a lengthy and costly process. The aforementioned diversity of member countries further complicates and hinders its smooth implementation. Despite the many barriers and impediments, efforts to achieve these goals are being carried out with increasing intensity. However, individual countries remain at very different stages in the implementation of the various tasks involved.

The results of many studies to date indicate that the leaders in areas such as the development of RES—most often measured by the share of RES in total energy consumption, including transportation, heating and cooling, and

electricity—are primarily the countries of the so-called "old EU-14," led by the Scandinavian nations.^[13-17] This leadership also translates into greater energy independence and lower levels of greenhouse gas emissions. However, the EU's common economic policy and its stated goals require all member states to work toward their achievement. This includes less developed countries and those where the energy transition is progressing more slowly.

In order to assess the status and progress of these countries in achieving energy independence and climate neutrality, it becomes necessary to conduct research that evaluates this condition. Diagnosing the effectiveness of the implementation of EU energy policy—measured by the degree to which its goals and priorities are achieved—should serve as an important source of information for further research and policy development. Studying the dynamics of changes in indicators related to various areas of policy implementation can also provide new insights into building EU energy independence and achieving climate neutrality.

Undertaking the research is fully justified in light of the energy goals adopted by the EU. This justification is further reinforced by the fact that the topic has not yet been explored to the extent proposed in this work. Consequently, a clear research gap exists in assessing the implementation of EU energy policy. To address this gap and expand knowledge on the subject, this paper presents research findings aimed at evaluating the current level of implementation and effectiveness of energy policy in EU member states in a 10-year period (2013-2022). This assessment focused on issues related to energy independence, security, and climate neutrality. Achieving the stated goals is a complex challenge that requires analyzing multiple factors, including progress toward climate targets, changes in the energy mix, and energy supply security. To guide the research and ensure a structured approach, the following key questions were formulated:

Q1. To what extent was EU energy policy implemented across the EU-27 member states in 2013 and 2022?

Q2. How effective have the EU-27 countries been in meeting key energy policy objectives, particularly those tied to energy independence and climate neutrality?

To address the defined objective and formulated research questions, a tailored methodology was developed. Given the complex, multidimensional nature of evaluating EU energy policy implementation, a multi-criteria approach—drawing on methods from the multi-criteria decision making (MCDM) group—was employed. The study utilized statistical data from the databases of Eurostat, the International Energy Agency (IEA), and the World Bank Data. The data encompassed key characteristics of the studied countries, focusing on energy security (including energy independence) and environmental issues related to greenhouse gas emissions.

In addition, an evaluation criterion related to energy poverty was also included in the analysis, serving as an indicator of adverse effects stemming from the energy

transition process. Overall, the study utilized 13 distinct indicators. The relative importance of each evaluation criterion was determined through weight values calculated using objective methods, including criteria importance through inter-criteria correlation (CRITIC), statistical variance, equal weights, and Laplace’s criterion. The main evaluation, which involved calculating the index of efficiency of energy policy implementation (IEEPI), was carried out using MCDM methods: combinative distance-based assessment (CODAS), technique for order of preference by similarity to ideal solution (TOPSIS), and viekriterijumsko kompromisno rangiranje (VIKOR). Additionally, the Hurwicz criterion was applied in the evaluation process. The originality of the considerations and research presented in this paper is determined by the following factors:

- Development of a new and universal methodology for assessing EU energy policy implementation effectiveness, with particular focus on energy independence and climate neutrality. This approach enables comparative evaluation of the studied countries within a defined timeframe.
- Conducting a comprehensive assessment of energy policy implementation across EU-27 countries using efficiency indicators, including calculation of the IEEPI index and IEEPI-dynamics of change of indicators (IEEPI-DCI).
- Addressing a critical research gap by evaluating the effectiveness of energy policy implementation across EU member states.
- A comprehensive analysis of EU member states' key energy policy priorities - including energy security, climate

neutrality, and just transition mechanisms - within the framework of sustainable economic transformation.

The paper is structured as follows. Section 2 provides a review of the literature background relevant to the research topic. Section 3 details the research methodology, including: (1) the selected indicators, (2) the applied MCDM analytical methods, and (3) the procedure for calculating the IEEPI index. Section 4 presents the research findings, which are then discussed in Section 5 through comparative analysis with existing studies. Finally, Section 6 concludes the paper by summarizing key insights, acknowledging study limitations, and suggesting directions for future research.

2. Literature background and review of previous studies

When analyzing publications on EU energy policy, a noticeable shift in their focus becomes evident. In recent years, the policy has primarily been shaped by the imperative of ensuring energy security, including energy independence, and addressing environmental concerns. The energy and climate regulations adopted and implemented by the EU, in particular, play a crucial role in defining this policy direction (see Table 1).^[18-26]

The primary goal of EU energy policy is to build a stable, sustainable, and secure energy supply system across all member states. From an environmental perspective, this involves reducing greenhouse gas emissions, particularly CO₂, and minimizing the energy sector’s negative impact on the environment.^[27,28]

Table 1: Summary of the most relevant EU energy and climate regulations.

EU regulations	
In the field of energy	In terms of climate
Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. ^[18]	The Treaty on the Functioning of the European Union - Climate Component (Article 192(1)). ^[23]
Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency. ^[19]	Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814. ^[24]
Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. ^[20]	Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013. ^[25]
Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC. ^[21]	Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU. ^[26]
Regulation (EU) 2019/942 of the European Parliament and of the Council of 5 June 2019 establishing a European Union Agency for the Cooperation of Energy Regulators. ^[22]	

Research on the implementation of energy policy among EU countries covers a wide range of issues, including energy efficiency improvements, sustainable resource utilization, greenhouse gas emissions reduction, and enhanced national energy security. Much of the research focuses on analyzing, evaluating, and monitoring the progress toward achieving key energy targets, such as increasing the share of RES.^[13,15,28] Improving efficiency, independence, and energy security,^[16,17,29-32] and reducing greenhouse gas emissions.^[33,34] Włodarczyk *et al.*^[35] assessed the similarities among EU countries based on their 2019 performance in renewable energy use, energy productivity, energy independence, and greenhouse gas emissions. Using hierarchical clustering, the study revealed that Denmark, Sweden, and Finland ranked highest in these categories, while Cyprus, Belgium, Luxembourg, Malta, and Lithuania ranked lowest. Wang and Zhan analyzed renewable energy development across 18 EU countries from 2007 to 2016.^[12] Their findings indicated that Germany, the UK, France, and Italy achieved the most significant progress in this domain. Another study examines the renewable energy potential in the "new EU" member states.^[36] The findings reveal that all these countries pursued policies to increase electricity generation from renewable sources during the analyzed period (2004-2016), ultimately reaching very similar levels of production. Vavrek *et al.*^[14] analyzes the energy profiles of EU member states in relation to the European Energy Union priorities, particularly the reduction of greenhouse gas emissions from the energy sector. This analysis, conducted for the period 2008-2016, identified Austria, Denmark, Finland, France, Latvia, and Sweden as the top performers in this regard. Bórawski *et al.*^[15] investigated the RES potential across EU countries from 2004 to 2016. The study employed three methodological approaches to assess these changes: descriptive statistics, the extended Dickey-Fuller test (ADF test), and the generalized autoregressive conditional heteroscedasticity (GARCH) model. The analysis revealed that Malta (8,322%), the United Kingdom (1,126%), and Luxembourg (784%) demonstrated the most substantial growth in RES adoption during the study period.

A review of studies on RES development reveals consistent evidence of their significant positive impact on reducing GHG emissions in EU countries. Regarding the energy security of EU countries, most publications focus on diversifying energy supply and production while reducing dependence on conventional energy sources. A key priority in this context is maintaining energy stability, particularly by securing reliable gas supplies for member states.^[37-39] Matsumoto *et al.*^[40] and Radovanović *et al.*^[41] examined the energy security of EU member states from a supply perspective. In contrast, De Rosa *et al.*^[42] focused on assessing energy security through four key dimensions: (1) supply diversification, (2) import dependence, (3) market concentration, and (4) renewable energy adoption. Social and economic dimensions represent critical aspects of EU energy policy implementation. Consequently, research must examine the energy transition's impacts on key factors,

including employment,^[43] energy poverty,^[44-46] and energy affordability.^[47] The findings from these studies demonstrate that socioeconomic factors play a critical role in shaping public perception and acceptance of energy transition policies. The collected studies and their findings serve as valuable resources for evaluating the effectiveness of the EU energy policy. They also help identify key socioeconomic factors that influence such assessments. This study also identifies a research gap concerning comprehensive evaluations of all 27 current EU member states' progress toward energy independence and climate neutrality. Consequently, it underscores the need for further research to assess the effectiveness of EU-27 energy policies in these specific domains. The findings and conclusions from the literature review informed the development of policy and organizational recommendations for guiding future EU energy policy implementation.

3. Materials and methods

3.1 Characteristics of the indicators adopted for the study

Evaluating the effectiveness of energy policy implementation in the EU-27 is a complex process involving many issues. Therefore, a multi-criteria approach to this assessment was used. The research was based on a set of 13 indicators characterizing the following key elements of EU energy policy:

- Diversification of energy sources,
- Energy efficiency,
- The use of conventional and emission sources (gas, coal, and oil), conventional zero-emission sources (nuclear power), and the share of renewable sources in the energy mix,
- Dependence on imported energy,
- RES energy use in the transportation sector, heating and cooling, and electricity,
- Greenhouse gas emissions,
- Energy poverty levels.

All the indicators used for the study, along with their brief characteristics, are summarized in [Table 2](#).

3.2 Research methods

In order to assess the level of efficiency of energy policy implementation in the EU countries, a research methodology was developed that takes into account the multidimensionality of this process. Of key importance for the assessment of individual countries, in this regard, is the development and determination of the value of the aggregate IEEPI by individual EU countries. The determination of this index involves two main stages.

In the first stage, the weights of indicators characterizing the process under study are determined. In this regard, given the existence of numerous analytical (objective) methods for determining weights that can yield significantly different results, it was assumed that it is necessary to use at least two different methods and Laplace's criterion (a decision-making criterion under uncertainty).

Table 2: Characteristics of the indicators used in the study.

Indicator name	Designation	Characteristics of the indicator
Final energy consumption, tonnes of oil equivalent (TOE) per capita	X1	Improving energy efficiency is a major goal of EU energy policy. It affects the reduction of energy consumption, costs, and emissions of harmful substances.
Energy imports dependency, %	X2	This indicator refers to the share of imported energy in the total energy consumption of a country or region. The higher its value, the greater the proportion of energy consumed that is imported.
HHI Concentration	X3	This indicator determines the degree of diversification of energy sources in a country's energy mix. This process aims to reduce dependence on imported fossil fuels and increase energy security.
Energy sufficiency	X4	This indicator is a measure of a country's ability to meet its energy needs based on its own energy production. It is the ratio of a country's energy production to its energy consumption.
Share of non-renewables in energy mix (%)	X5	This indicator determines the share of traditional, conventional energy sources in the country's overall energy balance
Share of nuclear energy mix (%)	X6	This indicator determines the share of energy produced by nuclear power plants in a country's total energy balance
Share of renewables in energy mix (%)	X7	This indicator determines the share of energy generated by renewable sources in the country's total energy balance
Share of renewable energy in final energy consumption in transportation (%)	X8	This indicator determines the share of renewable energy in the total energy consumption of the transport sector. Renewable energy in transportation can be used as a source of vehicle propulsion, such as electric cars powered by electricity from renewable sources (<i>e.g.</i> , wind, sun), or as biofuels (<i>e.g.</i> , biodiesel, bioethanol) produced from organic plant materials or organic waste.
Share of electricity from renewable sources in gross final electricity consumption (%)	X9	This indicator determines the share of electricity generated from renewable energy sources in total electricity consumption.
Share of energy from renewable sources in heating and cooling (%)	X10	This indicator determines the share of thermal energy obtained from renewable energy sources for heating and cooling.
Total GHG per capita [t CO ₂ eq./capita]	X11	The indicator measures total greenhouse gas (GHG) emissions per capita, expressed in tons of carbon dioxide equivalent.
GHG Intensity of Energy [kg CO ₂ eq./toe]	X12	This indicator allows you to assess how much greenhouse gas emissions are relative to the amount of energy consumed, enabling environmental analysis of energy efficiency.
Population unable to keep home adequately warm by poverty status, %	X13	This indicator determines the size of the population that is unable to adequately heat its residence due to poverty. Such a condition can have negative social (impact on the health and well-being of the population), environmental, and economic consequences.

The application of Laplace's criterion in determining the weights of indicators plays a crucial role in ensuring balance between the results obtained from various objective methods. This approach allows each applied technique to contribute to the determination of weights, minimizing the risk of dominance by a single method and reducing the impact of its potential weaknesses. Averaging the results further enhances neutrality and increases resistance to random variability in the data. As a result, the weights are more balanced and can be more easily applied in different research or practical contexts

while ensuring the transparency of the process and greater reliability of the analysis. Simultaneously applying multiple methods leads to more credible results.

The number of analytical methods used for determining the weights of indicators in the presented approach can vary, but must not be less than two. Analytical methods for objectively determining weights rely on the mathematical analysis of input data, which avoids subjective influences from various factors. A diagram of this stage of the research is shown in Fig. 1.

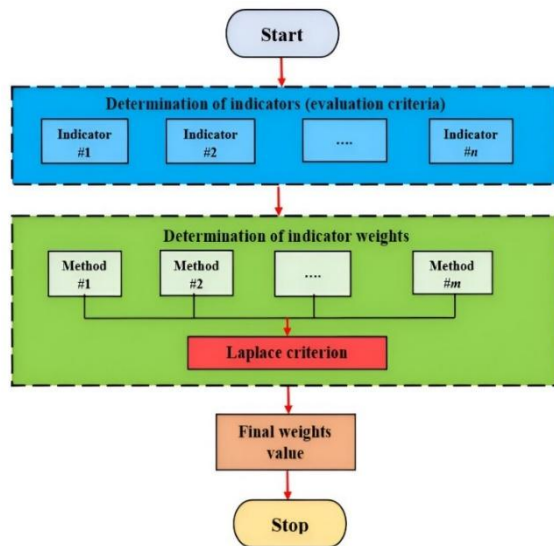


Fig. 1: General algorithm for determining the weights of the indicators adopted for the study.

In the work presented here, three objective methods were used to determine the weights of indicators: CRITIC, equal weights, and statistical variance, and the final value of these weights for each indicator was determined from Laplace’s criterion, Eq. (1):

$$w_j = \alpha \times w_{j_1} + \alpha \times w_{j_2} + \alpha \times w_{j_3} \quad (1)$$

where w_j are the final values of the weights of the indicators included in the study; w_{j_1} , w_{j_2} and w_{j_3} are the values of the weights of a given indicator obtained in each of the analytical methods; α is the equality coefficient (a value derived from Laplace’s criterion, which assumes that all values of the weights obtained in the analytical methods used are equally likely, since three analytical methods were used, each method has a weight of 0.33).

The second stage of research involves the selection of MCDM methods to determine the value of the method-specific evaluation index. In this stage, no fewer than two analytical methods should be selected. This approach is also due to the fact that MCDM methods, due to the use of different computational algorithms, often give different evaluation results. To eliminate this problem, the present research uses three MCDM methods and the Hurwicz criterion (a criterion for decision-making under uncertainty). A diagram of this stage of the research is shown in Fig. 2.

The CODAS, TOPSIS, and VIKOR methods were used to determine the value of indices of efficiency in the implementation of the EU energy policy. The evaluation index in each of these methods underwent a normalization process, which made it possible to reduce them to a comparable form. The indices were normalized according to Eqs. (2) and (3):

$$As_{ij} = \frac{x_{ij}-minx_{ij}}{maxx_{ij}-minx_{ij}} \quad (2)$$

For the MCDM method, the higher the evaluation index value, the better.

Or

$$As_{ij} = \frac{max x_{ij}-x_{ij}}{maxx_{ij}-minx_{ij}} \quad (3)$$

For the MCDM method, the lower the evaluation index value, the better.

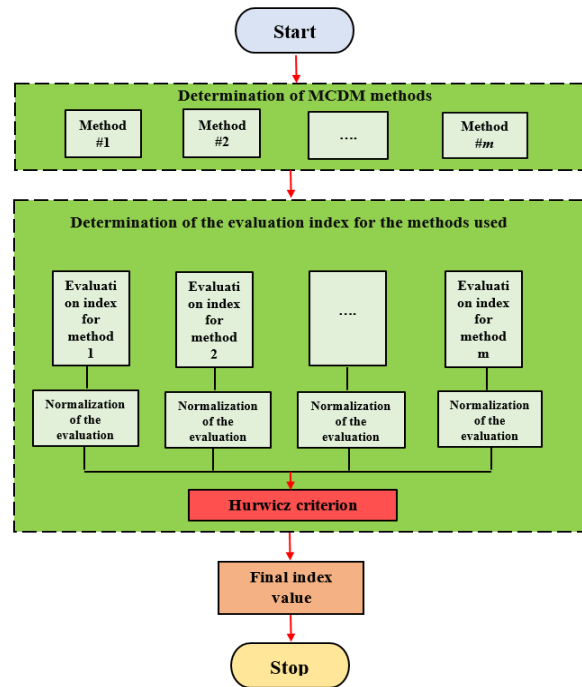


Fig. 2: General algorithm for determining the evaluation index of the effectiveness of EU energy policy implementation (IEEPI and IEEPI-DCI).

The normalized indices thus determined (in each of the methods used) were used in conjunction with the Hurwicz criterion to determine the values of the IEEPI and IEEPI-DCI, according to Eq. (4):

$$IEEPI = \lambda \times \text{maximum value of evaluation index in MCDM methods} + (1 - \lambda) \times \text{minimum value of evaluation index in MCDM methods} \quad (4)$$

where λ is the optimism coefficient in the range [0, 1]. In this study, we assumed a value of 0.5.

3.3 Characteristics of the methods used to determine the weights of the indicators

3.3.1 Equal weights method

In this method, each criterion has equal weight or importance in the decision-making process. Regardless of the variety of criteria, each criterion contributes equally to the evaluation of alternatives. The equal weights method is useful in situations where the decision maker has no preference for the importance of individual criteria, or where it is difficult to determine the weight for each criterion (insufficient information about the importance of the criteria).^[48,49] The determination of weight is based on this method, on the number of criteria included in the evaluation using Eq. (5):

$$w_j = \frac{1}{a} \tag{5}$$

where w_j is the importance of an indicator characterized by its weight, a is the number of indicators of the effectiveness of the implementation of energy policy.

3.3.2 Statistical variance method

The statistical variance method of determining weights involves assigning weights to different evaluation criteria based on their variance. This method takes into account the dispersion of data points around the mean value as an indicator of the importance of each evaluation criterion in the decision-making process. Criteria with higher variance are assumed to have a greater impact on the overall decision and therefore receive higher weights, while criteria with lower variance are given lower weights. The determination of weights follows the following steps in Eqs. (6)-(9).^[48,49]

- To create an initial decision matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \dots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \dots & x_{mn} \end{bmatrix} \tag{6}$$

- Based on the initial decision matrix, determine the normalized decision matrix:

$$X_{ij}^* = \begin{cases} \frac{x_{ij}}{\max_i x_{ij}} & \text{if } j \in N_b \\ \frac{\min_i x_{ij}}{x_{ij}} & \text{if } j \in N_c \end{cases} \tag{7}$$

where N_b and N_c are stimulants (benefit) and destimulants (cost), respectively.

- To calculate the statistical variance of information:

$$V_j = \left(\frac{1}{n}\right) \sum_{i=1}^n (X_{ij}^* - \bar{X}_{ij}^*)^2 \tag{8}$$

- To determine the value of the weights (w_{ij}) for the indicators:

$$w_{ij} = \frac{V_j}{\sum_{i=1}^n V_j} \tag{9}$$

3.3.3 CRITIC method

The CRITIC method focuses on evaluating the importance of individual criteria in the context of decision-making. It takes into account the standard deviation occurring between evaluation criteria and their correlation coefficient. Indicators characterized by a high degree of variability and, at the same time, a low relationship (correlation) with other indicators receive lower values of weights. The stages of determining the weights of indicators in this method are as follows:^[50]

- To create an initial decision matrix in Eq. (6);
- Based on the initial decision matrix, to determine the normalized decision matrix in Eq. (10) :

$$X^* = [r_{ij}]_{m \times n} \tag{10}$$

where $r_{ij} \in (0, 1)$.

Normalization of indicators-stimulants Eq. (11):

$$r_{ij} = \frac{x_{ij} - \min_j(x_{ij})}{\max_j(x_{ij}) - \min_j(x_{ij})} \tag{11}$$

Normalization of indicators-destimulants Eq. (12):

$$r_{ij} = \frac{\max_j(x_{ij}) - x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \tag{12}$$

- To calculate the value of the standard deviation (SD) for the normalized indicators Eq. (13):

$$SD = \sqrt{\frac{\sum_{i=1}^n (r_{ij} - \bar{r}_{ij})^2}{n-1}} \tag{13}$$

- To determine the values of the correlation coefficients (r_{jk}) between the normalized indicators Eq. (14):

$$r_{jk} = \frac{\sum_{i=1}^n (r_{ij} - \bar{r}_{ij})(r_{ik} - \bar{r}_{ik})}{\sqrt{\sum_{i=1}^n (r_{ij} - \bar{r}_{ij})^2 \sum_{i=1}^n (r_{ik} - \bar{r}_{ik})^2}} \tag{14}$$

- To determine the weights of the indicators from Eq. (15):

$$w_{ij} = \frac{G_j}{\sum_{i=1}^n G_j} \tag{15}$$

where G_j is a measure of the information capacity of the j -th criterion.

$$G_j = \sigma_j \sum_{i=1}^n (1 - r_{jk}) \tag{16}$$

3.4 Characteristics of the MCDM methods

3.4.1 CODAS method

In the CODAS method, the attractiveness of alternatives is determined using two measures. The main and primary measure is the Euclidean distance of the evaluated alternatives from the negatively ideal point. The second measure is the taxicab distance. The alternative with a greater distance from the negatively ideal point is better. If two alternatives are incomparable due to Euclidean distance (*i.e.*, the Euclidean distance of two alternatives is very close), then the taxicab distance is used as a secondary measure. The steps in determining the evaluation measure in this method are as follows:^[51,52]

- To create an initial decision matrix in Eq. (6);
- Based on the initial decision matrix, to determine the normalized decision matrix from Eq. (7);
- To determine the weighted decision matrix (r_{ij}), Eq. (17):

$$r_{ij} = n_{ij} \cdot w_{ij} \tag{17}$$

- To calculate the negative-ideal variant from Eqs. (18) and (19):

$$ns = [ns_j]_{1 \times m} \tag{18}$$

$$ns_j = \min_i r_{ij} \tag{19}$$

- To calculate the Euclidean distance (E_i) in Eq. (20) and

Taxicab distance (T_i) in Eq. (21) for each alternative from the negative-ideal alternative:

$$E_i = \sqrt{\sum_{j=1}^m (r_{ij} - ns_j)^2} \quad (20)$$

$$T_i = \sum_{j=1}^m |r_{ij} - ns_j| \quad (21)$$

- To determine the relative evaluation matrix of alternatives, Eqs. (22) and (23):

$$R_a = [h_{ik}]_{n \times n} \quad (22)$$

$$h_{ik} = (E_i - E_k) + (\psi(E_i - E_k) \times (T_i - T_k)) \quad (23)$$

where $k \in \{1, 2, \dots, n\}$, ψ is a threshold function to identify the equality of Euclidean distances of two alternatives and is determined as Eq. (24):

$$\psi = \begin{cases} 1 & \text{if } |x| \geq \tau \\ 0 & \text{if } |x| < \tau \end{cases} \quad (24)$$

where τ is a quantity set by the decision maker (between 0.01 and 0.05).

- To calculate the evaluation measure values for each alternative in Eq. (25):

$$H_i = \sum_{k=1}^n h_{ik} \quad (25)$$

3.4.2 TOPSIS method

The TOPSIS method is one of the techniques of multi-criteria decision analysis, used to select the best solution among a set of alternatives. It involves determining the distances of the decision alternatives under consideration from the ideal and anti-ideal solution. These distances are determined based on the Euclidean distance. The steps in determining the evaluation measure in this method are as follows:^[53]

- To create an initial decision matrix in Eq. (6);
- Based on the initial decision matrix, to determine the normalized decision matrix (n_{ij}) in Eq. (26):

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (26)$$

- To calculate the weighted decision matrix in Eq. (27):

$$v_{ij} = x_{ij} \cdot w_{ij} \quad (27)$$

where w_{ij} is the weight of the i -th criterion, $\sum_{i=1}^n w_i = 1$.

- To identify a positive ideal solution (v_j^+) in Eq. (28) and a negative anti-ideal solution (v_j^-) in Eq. (29):

$$v_j^+ = \{v_1^+, v_2^+, \dots, v_n^+\} = \{\max_j(v_{ij})\} \quad (28)$$

$$v_j^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \{\min_j(v_{ij})\} \quad (29)$$

- To calculate the Euclidean distance of alternatives from perfectly positive (D_i^+) in Eq. (30) and perfectly negative (D_i^-) in Eq. (31) solutions:

$$D_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad (30)$$

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (31)$$

- To calculate the so-called measure of relative proximity (P_i) of each alternative to the optimal solution in Eq. (32):

$$P_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (32)$$

3.4.3 VIKOR method

The VIKOR method is based on determining the distance of alternatives from the ideal scenario. This method introduces the so-called ranking index, which is based on the determination of the distance from the ideal solution. This index is an extension of the aggregate function theory in the compromise programming method. A multi-criteria measure for compromise ranking is developed based on the Lp metric used as an aggregate function in the compromise programming method. The output parameter for the VIKOR method is the Lp-metric distance, determined based on Eq. (33):^[54,55]

$$L_{pi} = \left\{ \sum_{i=1}^n \left[w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)^p} \right]^p \right\}^{\frac{1}{p}}; 1 \leq p \leq \infty, j = 1, 2, \dots, m \quad (33)$$

In the VIKOR method, $L_{1,i}$ (as S_i) and $L_{\infty,i}$ (as R_i) are used to formulate the ranking measure. The solution obtained by $\min S_i$ has maximum group utility ("majority rule"), and the solution obtained by $\min R_i$ has minimum individual "opponent" regret:

The steps of proceeding in the VIKOR method are as follows:

- To create an initial decision matrix in Eq. (6);
- Based on the initial decision matrix, to determine the normalized decision matrix in Eq. (10);
- To determine the best f_i^* and worst f_i^- values for all criterion functions $i=1, 2, \dots, n$. If the i -th criterion represents profit (the higher the value, the better), then we get Eq. (34):

$$f_i^* = \max_j f_{ij} \quad (34)$$

And if it represents cost (the smaller the value, the better), then in Eq. (35):

$$f_i^- = \min_j f_{ij} \quad (35)$$

- To calculate the values of S_i and R_i , which are used to determine the ranking measure in Eqs. (36) and (37):

$$L_{1j} = S_i = \sum_{i=1}^n w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \quad (36)$$

$$L_{\infty j} = R_i = \max \left[w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \right] \quad (37)$$

where w_i is the weight of the i -th criterion; S_i and R_i represent the measure of utility and the measure of regret, respectively. The solution obtained by $\min S_{ij}$ has maximum group utility

(majority rule), and the solution obtained by $\min R_{j\ m}$ has a minimum individual regret "opponent".

- To calculate Q_j measures using Eq. (38):

$$Q_j = \frac{v(S_i - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_i - R^*)}{(R^- - R^*)} \tag{38}$$

where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$, and v is a measure of strategic weight (takes a value from 0 to 1), in the study, it is assumed that $v = 0.5$.

4. Results

4.1. Evaluation of the implementation of the EU-27 energy policy according to the developed methodology

In order to achieve one of the objectives of the study and answer the first research question (RQ1), the values of the indices of the efficiency of the implementation of EU energy policy and the levels that EU countries had in this regard in 2013 and 2022 were determined. These values were determined based on the indicators adopted for the study.

In the first stage of the research, the weights of these indicators were determined. For this purpose, three objective methods for their determination and Laplace's criterion for decision-making under uncertainty were used. The results obtained for 2013 and 2022 are included in Table 3.

The results obtained (Table 3) indicate that the values of

the weights of the studied indicators varied in 2013 and 2022. In order to check the variability of these weights, the value of the coefficient of variation was determined for each indicator (Table 4).

The calculations showed that the highest variability was characterized by indicators X1, X2, X5, X6, X11, and X13. Their coefficients of variation exceeded the value of 10%. The value of the coefficient of variation exceeding 10% means that the studied variables are characterized by moderate variability. In order to eliminate the impact of differences in the values of the indicator weights, their average values from 2013 and 2022 were used for the final calculations. The final values of the weights adopted for the basic research are shown in Fig. 3.

The determined values of the weights indicate that the indicator "Share of nuclear energy mix" (X6) received the highest weight, while the indicator "Share of renewable energy in final energy consumption in transportation" (X8) received the lowest weight. Specifically, the weight values for these indicators were 0.921 and 0.677, respectively.

In the next stage of the research, the values of the index of the efficiency of implementation of the energy policy of each country in 2013 (IEEPI₂₀₁₃) and 2022 (IEEPI₂₀₂₂) were determined. These values allowed for the ranking of EU countries based on policy implementation effectiveness.

Based on the determined weights and using the CODAS,

Table 3: Values of indicator weights in 2013 and 2022.

Indicator	Values of indicator weights							
	2013				2022			
	CRITIC	Statistical variance	Equal weight	Value of criteria weights after applying the Laplace'a criterion	CRITIC	Statistical variance	Equal weight	Value of criteria weights after applying the Laplace'a criterion
X1	0.0706	0.0491	0.0769	0.0656	0.0653	0.0535	0.0769	0.0652
X2	0.0830	0.0978	0.0769	0.0859	0.1012	0.0720	0.0769	0.0834
X3	0.0696	0.0733	0.0769	0.0733	0.0694	0.0732	0.0769	0.0732
X4	0.0718	0.0890	0.0769	0.0792	0.0760	0.0786	0.0769	0.0772
X5	0.0851	0.0662	0.0769	0.0761	0.0858	0.0697	0.0769	0.0775
X6	0.0753	0.0983	0.0769	0.0835	0.0747	0.1015	0.0769	0.0844
X7	0.0714	0.0946	0.0769	0.0810	0.0722	0.1112	0.0769	0.0868
X8	0.0716	0.0586	0.0769	0.0691	0.0723	0.0531	0.0769	0.0674
X9	0.0896	0.0845	0.0769	0.0837	0.0834	0.1085	0.0769	0.0896
X10	0.0633	0.0848	0.0769	0.0750	0.0609	0.0931	0.0769	0.0770
X11	0.0649	0.0572	0.0769	0.0663	0.0665	0.0488	0.0769	0.0641
X12	0.0922	0.0626	0.0769	0.0772	0.0998	0.0641	0.0769	0.0803
X13	0.0916	0.0838	0.0769	0.0841	0.0726	0.0727	0.0769	0.0741

Table 4: Coefficients of variation of indicator weights determined by the Laplace criterion.

Indicator	X1	X2	X3	X4	X5	X6	X7
Coefficient of variation, %	18.0	15.1	0.4%	9.1%	10.1%	15.4%	8.8%
Indicator	X8	X9	X10	X11	X12	X13	
Coefficient of variation, %	1.8	5.8%	1.6%	11.0%	5.7%	10.5%	

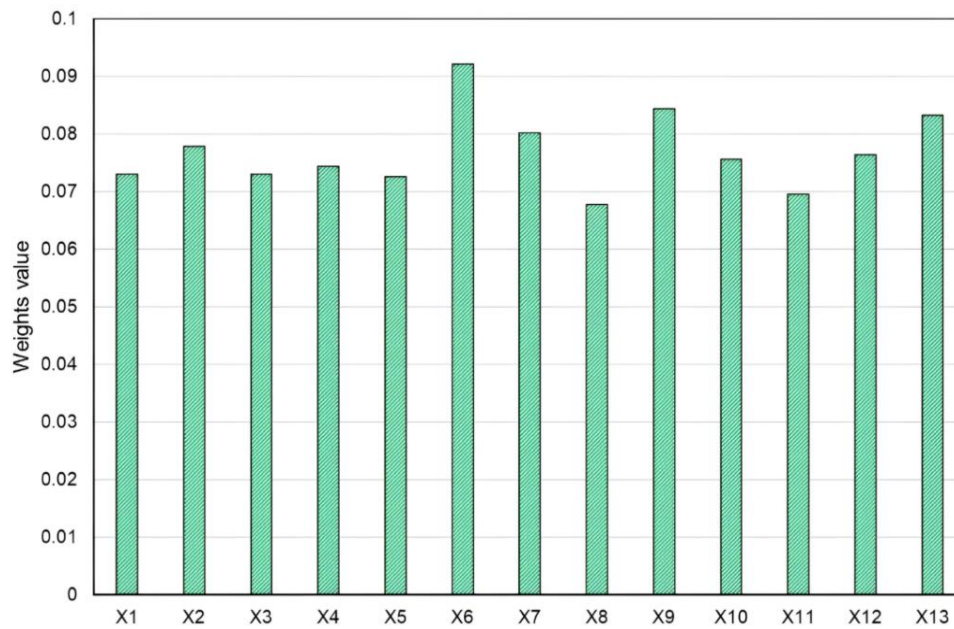


Fig. 3: Values of the weights of the indicators adopted to assess the effectiveness of the implementation of the EU-27 energy policy.

TOPSIS, and VIKOR methods, the values of the EU-27 energy policy implementation efficiency indices were calculated. These included the H_i index in Eq. (24) of the CODAS method, the P_i index in Eq. (31) of the TOPSIS method, and the Q_i index in Eq. (38) of the VIKOR method. The results of these calculations are presented in Tables 5 and 6.

Table 5: Summary of the values of the sub-indices and the rankings of the EU-27 countries based on them for 2013 data.

Country	CODAS		TOPSIS		VIKOR	
	Assessment score, H_i	Rank	Assessment score, P_i	Rank	Assessment score, Q_i	Rank
Belgium	-0.779	22	0.456	14	0.315	19
Bulgaria	0.234	10	0.425	18	0.298	15
Bohemia	-0.177	16	0.500	10	0.295	14
Denmark	1.064	3	0.536	6	0.247	8
Germany	-0.600	20	0.463	13	0.305	16
Estonia	0.310	9	0.437	16	0.375	21
Ireland	-1.484	26	0.356	23	0.419	24
Greece	-0.786	23	0.322	25	0.389	22
Spain	-0.393	17	0.456	15	0.276	12
France	0.449	7	0.593	3	0.202	5
Croatia	0.314	8	0.488	11	0.239	7
Italy	-0.655	21	0.400	21	0.309	17
Cyprus	-1.687	27	0.216	27	0.472	25
Latvia	0.863	4	0.506	9	0.195	4
Lithuania	-0.434	18	0.375	22	0.312	18
Luxembourg	-0.991	24	0.333	24	0.500	27
Hungary	-0.035	13	0.482	12	0.257	11
Malta	-1.276	25	0.245	26	0.477	26
Netherlands	-0.081	15	0.433	17	0.394	23
Austria	0.834	6	0.564	4	0.182	3
Poland	-0.518	19	0.412	19	0.369	20
Portugal	0.091	12	0.410	20	0.279	13
Romania	0.863	5	0.511	8	0.253	9
Slovenia	0.103	11	0.549	5	0.221	6
Slovakia	-0.076	14	0.518	7	0.254	10
Finland	1.541	2	0.638	2	0.155	2
Sweden	3.459	1	0.844	1	0.000	1

Table 6: Summary of the values of the sub-indices and the rankings of the EU-27 countries based on them for 2022 data.

Country	CODAS		TOPSIS		VIKOR	
	Assessment score, H_i	Rank	Assessment score, P_i	Rank	Assessment score, Q_i	Rank
Belgium	-0.653	19	0.393	15	0.330	18
Bulgaria	0.014	12	0.401	12	0.337	19
Bohemia	-0.174	13	0.413	10	0.330	17
Denmark	0.789	5	0.488	6	0.209	4
Germany	-0.631	18	0.362	17	0.323	15
Estonia	1.411	3	0.488	5	0.267	8
Ireland	-1.272	27	0.260	25	0.436	24
Greece	-0.699	21	0.270	24	0.394	22
Spain	-0.373	16	0.361	18	0.315	14
France	0.484	7	0.525	3	0.241	7
Croatia	0.123	11	0.412	11	0.267	9
Italy	-0.719	22	0.339	19	0.330	16
Cyprus	-1.197	26	0.225	27	0.479	26
Latvia	0.966	4	0.481	7	0.207	3
Lithuania	-0.365	15	0.337	20	0.340	20
Luxembourg	-0.856	24	0.254	26	0.500	27
Hungary	-0.420	17	0.398	14	0.309	12
Malta	-0.693	20	0.287	23	0.438	25
Netherlands	-0.977	25	0.324	21	0.382	21
Austria	0.780	6	0.461	8	0.215	5
Poland	-0.777	23	0.324	22	0.398	23
Portugal	0.267	9	0.388	16	0.280	10
Romania	0.159	10	0.400	13	0.310	13
Slovenia	0.274	8	0.499	4	0.232	6
Slovakia	-0.228	14	0.441	9	0.284	11
Finland	1.876	2	0.614	2	0.157	2
Sweden	3.031	1	0.840	1	0.000	1

The results show that the ranking position, which depends on the value of the evaluation index, for most EU countries varies depending on the method used for calculation. The same ranking position, achieved in 2013 by Sweden and Finland, was maintained in 2022 only by Sweden across all calculation methods used. While for some surveyed EU-27 countries, the differences in ranking positions are minimal, for others, they can be as significant as 12 positions. For instance, Estonia obtained the 9th ranking position in 2013 using the CODAS method but ranked 21st using the VIKOR method. These discrepancies highlight the substantial impact of the

calculation method on the final result, *i.e.*, the value of the evaluation index.

To mitigate this impact and obtain unambiguous results while considering different approaches to their determination, a calculation scheme was developed. This scheme is based on normalizing the indices determined by the CODAS, TOPSIS, and VIKOR methods, and then, using the Hurwicz criterion, determining the final value of the evaluation index. As per this procedure, the normalized evaluation index values obtained from the methods used were determined (Table 7).

Next, using the Hurwicz criterion (Section 3.2), the energy

Table 7: Normalized evaluation index values obtained from various methods.

Countries	2013			2022		
	CODAS	TOPSIS	VIKOR	CODAS	TOPSIS	VIKOR
	Assessment score, H_i	Assessment score, P_i	Assessment score, Q_i	Assessment score, H_i	Assessment score, P_i	Assessment score, Q_i
Belgium	0.176	0.382	0.370	0.144	0.273	0.339
Bulgaria	0.373	0.332	0.405	0.299	0.285	0.327
Bohemia	0.293	0.452	0.410	0.255	0.305	0.339
Denmark	0.535	0.510	0.506	0.479	0.427	0.581

Countries	2013			2022		
	CODAS	TOPSIS	VIKOR	CODAS	TOPSIS	VIKOR
	Assessment score, H_i	Assessment score, P_i	Assessment score, Q_i	Assessment score, H_i	Assessment score, P_i	Assessment score, Q_i
Germany	0.211	0.394	0.390	0.149	0.224	0.353
Estonia	0.388	0.352	0.250	0.624	0.427	0.465
Ireland	0.039	0.223	0.163	0.000	0.057	0.128
Greece	0.175	0.169	0.222	0.133	0.074	0.211
Spain	0.251	0.382	0.448	0.209	0.222	0.370
France	0.415	0.601	0.597	0.408	0.488	0.518
Croatia	0.389	0.433	0.521	0.324	0.304	0.465
Italy	0.201	0.294	0.382	0.129	0.186	0.341
Cyprus	0.000	0.000	0.056	0.017	0.000	0.042
Latvia	0.496	0.462	0.609	0.520	0.417	0.586
Lithuania	0.243	0.254	0.377	0.211	0.181	0.320
Luxembourg	0.135	0.186	0.000	0.097	0.048	0.000
Hungary	0.321	0.424	0.487	0.198	0.282	0.381
Malta	0.080	0.047	0.046	0.135	0.101	0.125
Netherlands	0.312	0.346	0.212	0.069	0.161	0.235
Austria	0.490	0.555	0.636	0.477	0.384	0.571
Poland	0.227	0.312	0.263	0.115	0.161	0.204
Portugal	0.345	0.310	0.442	0.358	0.265	0.440
Romania	0.496	0.470	0.494	0.333	0.285	0.380
Slovenia	0.348	0.530	0.558	0.359	0.446	0.536
Slovakia	0.313	0.481	0.493	0.243	0.351	0.432
Finland	0.627	0.673	0.690	0.732	0.633	0.687
Sweden	1.000	1.000	1.000	1.000	1.000	1.000

Table 8: Results of the correlation test between the determined values of the evaluation indices for the 2013 data.

Methods	CODAS	TOPSIS	VIKOR	Hurwicz criterion
CODAS	1.000	0.911	0.882	0.968
TOPSIS	0.911	1.000	0.933	0.963
VIKOR	0.882	0.933	1.000	0.969
Hurwicz criterion	0.968	0.963	0.969	1.000

Table 9: Results of the correlation test between the determined values of the evaluation indices for the 2022 data.

Methods	CODAS	TOPSIS	VIKOR	Hurwicz criterion
CODAS	1.000	0.864	0.832	0.949
TOPSIS	0.864	1.000	0.929	0.960
VIKOR	0.832	0.929	1.000	0.955
Hurwicz criterion	0.949	0.960	0.955	1.000

policy implementation efficiency indexes for 2013 (IEEPI₂₀₁₃) and 2022 (IEEPI₂₀₂₂) were determined (Fig. 4). Using the normalized values of the evaluation indices, gained from the CODAS, TOPSIS, and VIKOR methods, and after applying the Hurwicz criterion, the correlations between these results were checked. The determined values of Pearson's correlation coefficient are presented in Tables 8 and 9. The results indicate that the normalized values of the evaluation indices determined by the Hurwicz criterion coincide to a very high degree with the results obtained from the other methods. The determined ranking of the EU-27 countries in terms of the current (in a given year) state of energy policy implementation shows that in 2013 and 2022, Sweden was the leader, with Finland as the runner-up (see Fig. 4). Sweden

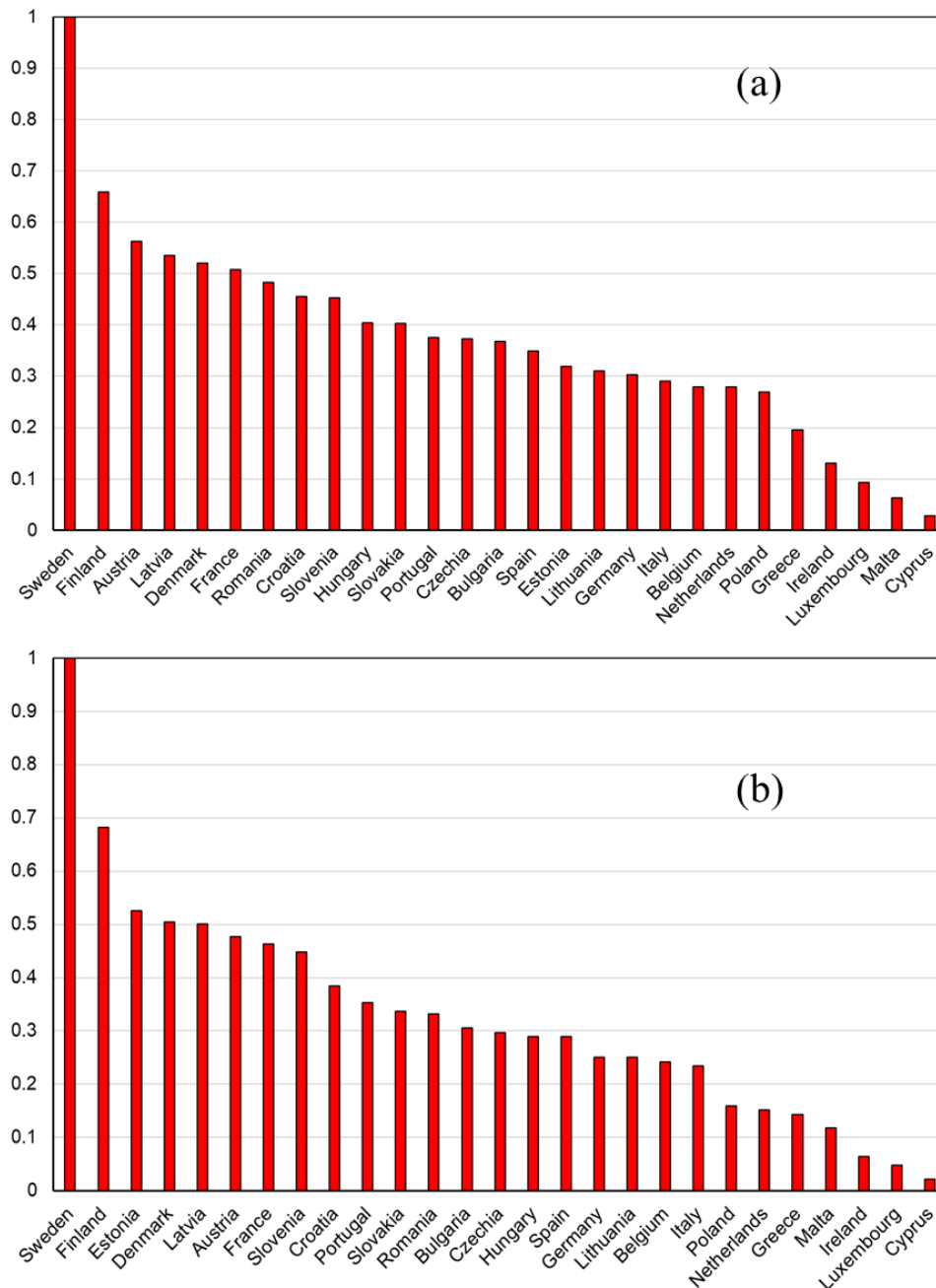


Fig. 4: Values of energy policy implementation efficiency indices in the EU-27 in 2013 (a) and 2022 (b).

received the highest possible rating index of 1 in both years, signifying its clear leadership in the effective implementation of EU energy policy. Finland, the second-ranked country, had significantly lower scores, with 0.66 in 2013 and 0.69 in 2022, respectively. However, the difference between Finland and the next-ranked country was not as significant. These results underscore Sweden's strong performance, attributed mainly to its high share of RES in the energy mix and consumption, as well as low greenhouse gas emissions.

Other countries such as Austria, Denmark, Estonia, and Latvia also achieved commendable results. Conversely, Cyprus ranked last in the ranking. Estonia showed the most significant rise in the ranking between 2013 and 2022, climbing by 13 positions, while Romania and Hungary

experienced the most significant falls, dropping by 5 positions. Five countries - Greece, Cyprus, Slovakia, Finland, and Sweden - maintained their ranking positions throughout the studied years.

Based on the values of the indices of efficiency of energy policy implementation, the levels that the EU-27 countries had in 2013 and 2022 were determined (see Fig. 5), according to the following criteria in Eqs. (39)-(42):

Level I, or Energy policy implementation leader:

$$AS_i > \overline{AS}_i + s_{AS_i} \tag{39}$$

Level II, or Strong energy policy implementer:

$$\overline{AS}_i + s_{AS_i} \geq AS_i > \overline{AS}_i \tag{40}$$

Level III, or Medium energy policy implementer:

$$\overline{A_{st}} > A_{si} \geq \overline{\overline{A_{st}}} - s_{A_{si}} \tag{41}$$

Level IV, or Weak energy policy implementer:

$$A_{si} < |\overline{A_{st}} - s_{A_{si}}| \tag{42}$$

where A_{si} is the evaluation index for the country, $\overline{A_{st}}$ is the average value of the evaluation index for the 27 EU countries, and $s_{A_{si}}$ is the value of the standard deviation of the evaluation index from its average value for 27 countries.

The classification of the EU-27 countries showed that in 2013, the leaders in implementing energy policy were two countries: Sweden and Finland, and in 2022, Estonia joined these countries. On the other hand, the weakest results were obtained by Ireland, Luxembourg, Malta, and Cyprus.

As mentioned earlier, Sweden and Finland are leaders due to the high share of RES in their energy mix and zero-emission renewable energy, as well as the use of RES in transport, heating, and cooling, and electricity. Both countries significantly invest in RES such as wind, hydro, and biomass energy. The high share of this energy results in very low levels of GHG emissions per capita and the intensity of GHG emissions from the energy sector. In Finland, the situation is slightly less favorable in terms of GHG emissions per capita, as they are relatively high. Some of the highly developed industrial sectors, such as the metallurgical and chemical industries, are significant sources of greenhouse gas emissions. The transport sector also generates considerable greenhouse

gas emissions in Finland due to the large number of combustion-engine cars and the long distances traveled. Climate conditions also necessitate intensive heating of buildings, which often leads to high energy consumption and greenhouse gas emissions associated with heat energy production.

The final evaluation of Finland and Sweden is also influenced by the situation in these countries in terms of energy security, which is relatively high. Both Sweden and Finland use a variety of energy sources, including nuclear, hydro, wind, biomass, and geothermal energy. This diversity helps minimize risks associated with unpredictable changes in energy supply. These countries are also largely energy-independent because they produce a significant portion of their energy from domestic sources, reducing their reliance on energy imports. The aforementioned RES also plays an irreplaceable role in this context. Therefore, it is obvious to recognize Sweden as an example to follow in terms of energy transition and striving for climate neutrality.

Cyprus received the worst evaluation results for energy policy implementation in both 2013 and 2022. The country is taking measures to adjust its energy policy to address the challenges of reducing greenhouse gas emissions, increasing the share of RES, and improving energy efficiency. However, compared to other EU countries, Cyprus faces challenges due to its specific geographical situation and energy infrastructure.

Among the EU countries, it is also worth noting the poor evaluation Ireland received in the studied years. Ireland has

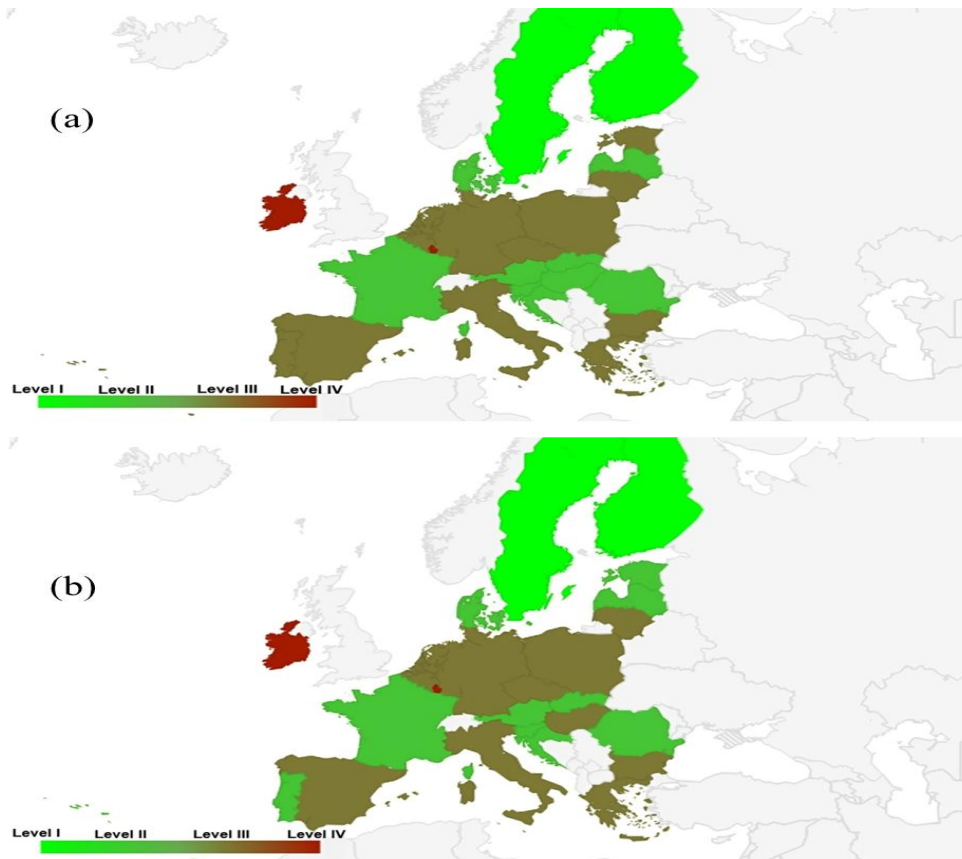


Fig. 5: Levels of EU-27 countries in terms of efficiency of energy policy implementation in 2013 (a) and 2022 (b).

energy sources such as oil and natural gas. Consequently, it is highly dependent on imported fossil fuels (over 90% in 2013 limited natural resources, particularly in terms of traditional and 77% in 2022), placing it in a more difficult position than countries with energy resources. Although Ireland has set ambitious goals for renewable energy use, aiming to achieve 70% electricity generation from renewable sources by 2030, this goal currently seems very challenging to reach. The share of RES in the energy mix was 6.5% in 2013 and only 8% in 2022. Meanwhile, the use of energy from RES was 7% in 2013 and 13% in 2022.

4.2 Evaluation of the effectiveness of energy policy implementation among the EU-27 countries on the basis of the values of the indices of the dynamics of change for the adopted indicators between the years 2013 and 2022

In the next stage of the study, an assessment of the effectiveness of the implementation of the energy policy of the

EU-27 countries was carried out based on the values of the indexes of the dynamics of change of the indicators adopted for the study. The index is a measure that informs about the change (increase/no change/decrease) in the value of the studied phenomenon over a specified period of time in relation to the initial period. This new approach to the study of the effectiveness of the implementation of the energy policy of the EU-27 countries provides an opportunity for an additional assessment of the changes that have occurred in these countries during the period under study. **Table 10** summarizes the calculated values of the indexes of the dynamics of change of the indicators adopted for the study, characterizing the effectiveness of the energy policy of the EU-27 countries in 2013-2022.

Referring to the values of the indexes of the dynamics of change of the studied indicators (see **Table 10**), notable trends emerge regarding energy efficiency and security across EU-27 countries. Luxembourg demonstrated the highest efficiency in

Table 10: Values of indexes of the dynamics of change of the indicators adopted for the study, in the EU-27 countries between 2013 and 2022.

Country	Indicators												
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
	%												
Belgium	94	91	132	119	101	92	108	202	207	121	89	88	88
Bulgaria	122	94	136	108	100	102	98	129	115	103	104	88	50
Bohemia	108	145	129	88	100	95	106	112	113	138	90	93	47
Denmark	94	100	138	66	94	0	118	163	169	142	73	83	134
Germany	91	102	143	93	99	98	110	111	174	116	79	91	126
Estonia	97	10	101	105	82	0	220	2478	225	142	57	74	117
Ireland	97	84	115	122	98	0	123	90	174	95	95	96	72
Greece	103	120	128	63	100	0	103	450	169	113	78	85	63
Spain	97	99	147	105	101	100	95	968	128	125	88	91	214
France	89	92	120	95	98	101	103	109	146	136	86	97	162
Croatia	114	115	129	80	102	0	95	257	127	102	103	96	71
Italy	98	96	130	102	100	0	100	187	115	110	91	94	47
Cyprus	100	93	90	197	99	0	111	638	223	189	103	97	63
Latvia	112	69	111	138	99	0	102	160	106	116	105	96	34
Lithuania	125	97	114	112	99	0	106	134	162	132	108	90	60
Luxembourg	83	95	100	279	98	0	143	195	267	242	89	108	131
Hungary	117	108	143	88	104	96	87	97	207	76	110	94	32
Malta	92	93	72	510	98	0	239	301	614	213	76	102	32
Netherlands	86	246	118	41	99	135	120	168	336	196	81	90	183
Austria	95	85	116	104	101	0	99	98	107	99	91	96	100
Poland	120	154	99	79	100	0	103	85	161	147	102	91	43
Portugal	100	91	126	119	99	0	102	931	119	123	89	91	63
Romania	122	173	147	84	100	96	101	164	114	94	101	90	103
Slovenia	96	102	140	92	98	111	95	282	106	100	85	91	53
Slovakia	102	90	140	101	99	98	114	141	108	248	97	92	131
Finland	99	76	151	117	97	96	107	194	130	103	74	75	117
Sweden	91	65	120	113	94	97	108	187	123	111	78	89	367
EU-27 Average	102	103	124	123	98	49	115	334	176	134	90	91	100

reducing final energy consumption per capita, achieving a notable decrease of 17%. Conversely, Lithuania experienced a significant increase of 25% in this indicator, with similar upward trends observed in Bulgaria, Czechia, Greece, Croatia, Latvia, Hungary, Poland, Romania, and Slovakia. Regarding dependence on imported energy sources, Estonia exhibited the most substantial decrease, with a remarkable 90% reduction. In contrast, the Netherlands saw a notable increase of over 150% in this dependence. Similar upward trends were observed in the Czech Republic, Germany (with a minimal increase of 1.5%), Greece, Croatia, Hungary, Poland (with an increase of over 50%), Romania (with an increase of over 70%), and Slovenia (with an increase of 2.5%).

Energy self-sufficiency is a crucial factor in enhancing energy security. Malta made significant progress in this regard between 2013 and 2022. Conversely, the Netherlands experienced a decrease in self-sufficiency due to increased energy imports. Eliminating non-renewable sources from the energy mix is essential for achieving climate neutrality. Estonia demonstrated the highest efficiency in this aspect, achieving an 18% reduction in non-RES, leading to substantial reductions in greenhouse gas emissions per capita (by 43%) and GHG intensity of energy (by 26%). Additionally, Estonia ranked as the second most effective country in increasing the share of RES in the energy mix, following Malta. Improving energy poverty levels is crucial from a social perspective. Malta and Hungary achieved the best results in reducing energy poverty levels, recording a notable 68% reduction. Conversely, Sweden experienced a nearly threefold increase in energy poverty.

In the subsequent phase of the study, based on the developed methodology and algorithms, the EU-27 energy policy implementation efficiency index (IEEPI-DCI) between 2013 and 2022 was determined using the values of the indexes of the dynamics of change of the studied indicators (refer to Table 10). The results are depicted in Fig. 6a. Furthermore, the division of EU-27 countries into groups with varying levels of efficiency was determined based on these indices, as shown in Fig. 6b. The evaluation criteria in this context were the values of the indexes of the dynamics of change of individual indicators as summarized in Table 10.

The results indicate that between 2013 and 2022, Malta, Estonia, Slovenia, and Hungary achieved the best outcomes in terms of energy policy implementation efficiency, with index values above 0.59. Conversely, Lithuania, Croatia, Denmark, and Austria demonstrated the lowest efficiency, with index values below 0.15. These countries represent the leaders and laggards, respectively, in terms of energy policy implementation efficiency (see Fig. 6b). Countries with index values ranging from 0.58 to 0.40, such as the Netherlands, Bulgaria, Luxembourg, Czechia, Slovakia, Spain, Ireland, Finland, Germany, France, and Belgium, performed strongly in achieving energy policy goals between 2013 and 2022. On the other hand, Cyprus, Greece, Italy, Romania, Latvia, Sweden, Portugal, and Poland were classified as moderately

effective in this process, with evaluation index values ranging from 0.449 to 0.2. Of particular interest are the border countries, which represent the most and least effective in implementing EU energy policy. These findings provide valuable insights into the varying degrees of success in energy policy implementation across EU member states and underscore the importance of tailored strategies to address specific challenges and opportunities in each country.

Malta, despite being the smallest country in the EU-27, showcased remarkable achievements in energy policy implementation between 2013 and 2022. Notably, Malta reduced its final energy consumption per capita by nearly 10%, a feat matched only by Germany and Sweden. Outperforming the majority of EU-27 countries, Malta ranked among the top performers in this aspect alongside the Netherlands, Luxembourg, and France. Moreover, Malta significantly bolstered its energy security by boosting energy self-sufficiency, achieving the highest performance in the EU-27. This remarkable progress was fueled by a substantial increase in the share of RES in the energy mix, effectively reducing dependence on imported energy sources. Malta's doubling of the share of RES energy in the energy mix contributed to this enhanced energy security. Furthermore, Malta demonstrated commendable advancements in the utilization of renewable energy in transportation, heating, cooling, and electricity. Notably, Malta recorded a threefold increase in the share of renewable energy in final energy consumption in transport, ranking among the top performers alongside Estonia.

Additionally, Malta achieved a sixfold increase in renewable energy use in electricity production, marking the best result in the EU-27. Moreover, Malta more than doubled its utilization of renewable energy in heating and cooling, ranking second only to Slovakia. In terms of greenhouse gas (GHG) emissions reduction efficiency, Malta, akin to Estonia, achieved impressive results, reducing GHG emissions per capita by 25%. This significant reduction underscores Malta's commitment to combating climate change and transitioning towards a sustainable energy future. Additionally, Malta made substantial strides in alleviating energy poverty, achieving a notable 47% reduction, the second-best result in the EU-27 after Ireland's 60% reduction. These achievements underscore Malta's holistic approach to energy policy, emphasizing energy efficiency, security, renewable energy development, GHG emissions reduction, and social welfare. Ultimately, Malta's exemplary performance in improving energy efficiency, enhancing energy security, developing RES, reducing GHG emissions, and mitigating energy poverty propelled it to the forefront of energy policy implementation within the EU-27.

Estonia achieved the second-highest index score in terms of the effectiveness of energy policy implementation during the studied period. Among the criteria considered in the evaluation, this country stands out notably from the others, particularly in improving energy security. The Estonian energy mix is not very diverse, as conventional sources (oil shale)

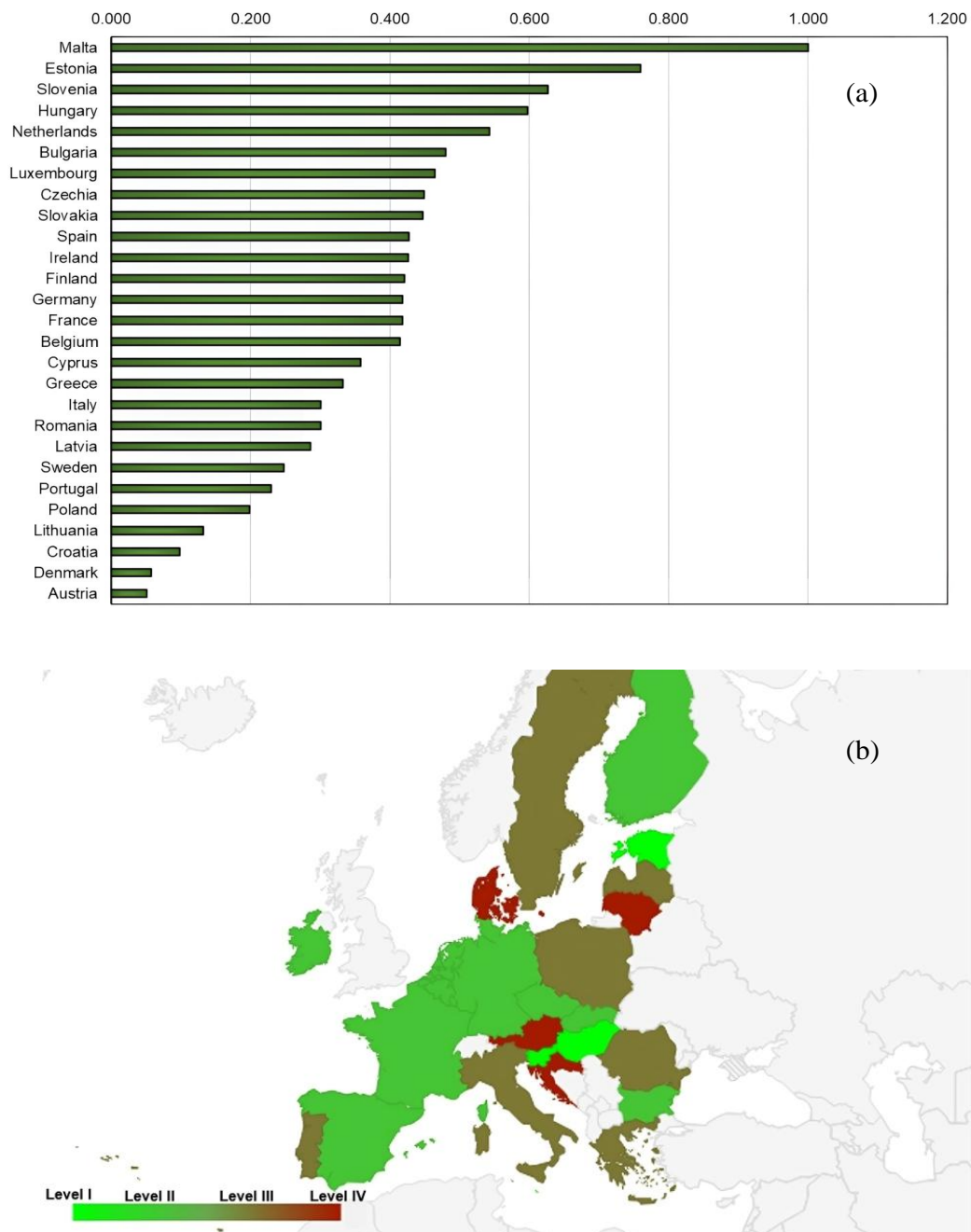


Fig. 6: Determined values of the IEEPI-DCI in the EU-27 countries between 2013 and 2022 (a) and their division into different levels of this efficiency (b).

dominate it. However, their share in this mix decreased by 19% during the studied period, which is the best result among all EU-27 countries. At the same time, the share of energy from RES more than doubled, which is the second-best result among EU countries (after Malta). Estonia also distinguishes itself with the most effective approach to becoming independent of imported energy sources. The country also achieves excellent results in reducing greenhouse gases per capita and the GHG Intensity of Energy. The dynamics of these changes during the studied period are negative, placing Estonia first in the EU-27 in this regard. Additionally, in terms of increasing the consumption of energy from renewable sources in transport, heating, cooling, and electricity, Estonia achieved some of the highest results among EU-27 countries.

The high ranking of this country is therefore mainly the result of the rapid reduction of greenhouse gases and the development of the use of energy from renewable sources in the key sectors included in energy directives.

Austria exhibited the poorest performance in implementing the EU-27 energy policy during the review period, attributed to several contributing factors. Firstly, there was an unfortunate increase in the share of non-renewable sources in Austria's energy mix, leading to a decline in the proportion of renewable sources. This trend hindered improvements in mix diversification, reflecting a negative development despite marginal differences. Additionally, there was a decrease in renewable energy consumption in the transportation sector and heating and cooling domains.

Most of the countries classified as strong in terms of the effectiveness of implementing the EU-27 energy policy (Netherlands, Luxembourg, Czechia, Slovakia, Spain, Ireland, Finland, Germany, France, and Belgium) reduced their greenhouse gas emissions per capita and the intensity of emissions from the energy sector. Only Bulgaria experienced a 5% increase in GHG emissions per capita; however, the intensity of emissions from the energy sector decreased by 10%. In Spain and Bulgaria, the share of energy from renewable sources in the energy mix decreased by 5% and 1.5%, respectively, during the analyzed period, which is an unfavorable trend, accompanied by a slight increase in the share of non-renewable sources. Regarding energy security, the situation worsened in Germany, Czechia, and the Netherlands, which increased their dependence on imported energy sources, leading to a decline in energy self-sufficiency in these countries.

When referring to the results of this part of the study, it is essential to note that countries that had high or low values of the adopted indicators (stimulators or inhibitors) at the beginning of the study (2013) had less potential for spectacular improvement than countries with low (stimulators) or high (inhibitors) values. This asymmetry stems from the fact that correcting poor results can be achieved with relatively low investments and limited resources, whereas striving for further improvement of already high indicators often requires significantly more effort and resources. The ranking of countries that performed the best and the worst in terms of the effectiveness of implementing the EU-27 energy policy across various criteria (values of index dynamics of indicator changes) during the studied period is presented in Table 11.

5. Discussion

The European Union's energy policy is shaped by a number of factors that take into account the goals, values, and challenges of access to energy sources, climate change, and sustainable development. Among the key objectives of the policy are ensuring energy security and diversification of energy sources for member countries. Also very important is the development of RES and the reduction of greenhouse gas emissions, as well as the reduction of energy poverty among the population. Comprehensive measures taken by the European Union are designed to create the right conditions for achieving these goals, *i.e.*, building energy independence and a low-carbon economy. Increasing the share of energy produced from RES in the energy mix and energy consumption is crucial.

In general, the EU's energy policy is accepted by member states, despite the differences between them.^[56] These are the result of the different wealth of the member countries and the historical background related to the structure of the energy sources used and, in many cases, still used by individual countries. Also related to this are the social and economic problems of many countries transforming their economies and energy. Therefore, research on the evaluation of the implementation of the EU-27 energy policy, which applies to all member countries, is very important. The achievement of its goals should therefore be realized by all these countries.

Previous studies in this regard have looked at individual elements of this policy and referred to selected areas of energy transition processes. Their results indicate that Scandinavian countries are the leaders in implementing these assumptions. This is especially true of energy consumption from renewable sources, energy independence, or the small share of

Table 11: The best and worst-rated EU-27 countries in terms of efficiency of energy policy implementation by criteria.

Evaluation criterion	Best results	Worst result
Final energy consumption, tonnes of oil equivalent per capita	Luxembourg	Lithuania
Energy imports dependency (%)	Estonia	Netherlands
HHI	Malta	Finland
Energy sufficiency	Malta	Netherlands
Share of non-renewables in energy mix (%)	Estonia	Romania
Share of nuclear energy mix (%)	Netherlands	Denmark, Estonia, Ireland, Greece, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Austria, Poland, Portugal
Share of renewables in the energy mix	Malta	Hungary
Share of renewable energy in final energy consumption in transportation (%)	Estonia	Poland
Share of electricity from renewable sources in gross final electricity consumption (%)	Malta	Latvia
Share of energy from renewable sources in heating and cooling (%)	Malta	Hungary
Total GHG per capita (t CO ₂ eq./capita)	Estonia	Hungary
GHG Intensity of Energy (kg CO ₂ eq./toe)	Estonia	Luxembourg
Population unable to keep home adequately warm by poverty status (%)	Malta, Hungary	Sweden

non-renewable sources in the energy mix.^[13-17,29,57] Good results are also achieved by some countries of the so-called "old EU-14" and those located in the central-eastern part of Europe (e.g., Latvia, Slovenia).

The comprehensive approach presented in this work for assessing the effectiveness of EU-27 countries' energy policy implementation offers broader insights into its analysis and facilitates comparisons of its current state among individual countries, along with evaluating the dynamics of change over the past decade. This approach encompasses both the accomplishments of individual countries and the evolution of the indicators studied, reflecting the areas they represent. By employing these two approaches, the study enables a comparison of the results obtained.

Regarding the first approach utilized in the study, which employs MCDM methods to examine the effectiveness of EU-27 countries' energy policy implementation from 2013 to 2022, the results align with findings from prior research.^[13,14,16,17,35,36] They affirm that Sweden and Finland achieved the most favorable outcomes in the studied area. Additionally, commendable results were observed among the "old EU-14" countries and several from the "new EU-13" group. Conversely, certain "new EU-13" countries, along with Luxembourg, Ireland, Malta, and Cyprus, exhibited poorer performance. These findings suggest that factors associated with the developmental stage of individual countries are less influential in their ability to meet EU energy objectives. This contradicts previous assumptions, prevalent in other scientific studies, that emerging and developing economies in the east (the "new EU-13" countries) encounter greater challenges in attaining energy and environmental 7 goals compared to developed nations.^[58-60]

The division of the EU-27 countries based on the survey indicates that the energy sector in several countries that joined the EU after 2004 is in a robust state, showing increasing effectiveness in meeting EU energy and climate policy objectives. This progress is notably evident in countries like Latvia, Croatia, Estonia, Romania, Slovenia, and Slovakia, where the proportion of energy derived from non-renewable sources in the energy mix is declining, and energy security is notably improving. These positive trends extend to highly developed nations such as Sweden, Germany, Denmark, and Greece, which are also demonstrating visible advancements in this regard.

A pivotal factor in energy transition processes is the proportion of energy derived from renewable sources in individual countries' energy mixes. Unfortunately, among both the "old EU-14" and "new EU-23" countries, there are instances where the share of non-RES in these mixes remains alarmingly high, hindering the attainment of policy objectives. Consequently, these countries exhibit significant greenhouse gas emissions per capita. This group includes nations such as Poland, Ireland, Luxembourg, Malta, and the Netherlands, among others.

The analysis presented here underscores the significance of

the results obtained from studying the index of the dynamics of change of individual indicators. These findings clearly demonstrate the progress made in many countries, particularly in the "new EU-13," in implementing EU energy policy. The relative gains in this index are most pronounced in these nations.

The study reveals that Malta and Estonia achieved the most favorable results, while Denmark and Austria exhibited the weakest performance. However, it's important to consider the relativity of these outcomes. More developed countries, primarily from the "old EU-14" group, though achieving commendable results in implementing EU energy policy, may record lower increases in this assessment due to their higher initial indicator values in 2013. The starting point in 2013 significantly influences the final outcome in this context. Nonetheless, this analysis, spanning a decade, provides insights into the dynamic changes occurring in each country. Malta serves as a compelling example, emerging as the leader in efficiently increasing the share of RES in the energy mix. Malta achieved a 350% efficiency compared to 2013, resulting in an actual 2% increase in RES share in the mix (from 1.5% to 3.5%). Despite the modest percentage increase, this accomplishment is substantial for Malta, considering its small size and the shaping of its energy system and infrastructure. Noteworthy investments in photovoltaic installations, wind farms, and other modern RES technologies have propelled the development of the country's renewable energy sector.

Moreover, the implementation of EU energy policy in the EU-27 is influenced by the goals and priorities set at the national level. Western and northern EU countries such as Germany, Sweden, Denmark, Spain, Portugal, and the Netherlands prioritize the development of RES to ensure climate neutrality and energy security. Sweden, a long-standing advocate for RES development, has significantly bolstered its energy security.^[16] The country has set ambitious targets, aiming for climate neutrality by 2045 and transitioning to 100% RES-based energy production by 2040.

Denmark is targeting 100% CO₂ neutrality by 2050 and plans to eliminate coal from its energy mix by 2030. Rapid RES development is expected to play a pivotal role in achieving these goals and ensuring energy security. Similarly, the Netherlands aims to generate 100% of its electricity from RES by 2050, necessitating the closure of coal-fired power plants. Spain is also eyeing 100% RES electricity production by 2050, with plans to shut down coal-fired plants by 2025. Portugal intends for 80% of its electricity to come from RES by 2030. Conversely, Germany, a major European economy, seeks to increase the proportion of renewables in its energy mix under its Energiewende policy.

Meanwhile, countries like Lithuania, Latvia, Estonia, and Poland prioritize enhancing energy security through RES and nuclear power development due to their heavy reliance on energy imports and raw materials. Poland, with its substantial coal dependence and reliance on natural gas imports, is actively diversifying its energy sources and plans to construct

its first nuclear power plant. The Baltic states (Estonia, Latvia, Lithuania) share similar energy import dependencies, stemming from their central planning legacy and reliance on imported resources.^[60] Political dynamics also significantly influence energy policy formation in these countries. For instance, RES development and climate neutrality were not top priorities in Poland's policy agenda from 2015 to 2023.^[61] Nonetheless, energy independence and security remain critical for the EU's overall economic and social development. Challenges such as dwindling conventional energy resources, rising energy demand, and geopolitical tensions, exemplified by the conflict in Ukraine, underscore the need to diversify energy sources, including RES, nuclear power, and green hydrogen production.

In the context of political and economic conditions and the pursuit of climate neutrality and independence, the study underscores the critical importance of the efficiency of implemented energy policies for the further development of the EU-27. Notably, the study reveals that factors related to gross domestic product (GDP) per capita have diminishing influence on this efficiency, as indicated by the results presented in Table 12. This trend suggests significant shifts in investment structures, economic development, and policy priorities across EU-27 countries. Previous research has indeed established correlations between economic growth, as measured by GDP and GDP per capita, and various energy-related indicators such as greenhouse gas emissions, energy consumption levels, and the utilization of RES.^[62-65] It can be inferred that energy-related issues are increasingly becoming central to the EU-27's economic agenda.

Table 12: Summary of the correlation coefficients between GDP per capita values and IEEPI-DCI indices in the EU-27 countries in 2013, 2022, and the entire period (2013-2022) studied.

Determined correlation	Spearman	p	Kendall	p
IEEPI ₂₀₁₃₋₂₀₂₂ and the value of the level of GDP per hybrid	-0.219	0.273	-0.218	0.349
IEEPI ₂₀₁₃ and the value of GDP per capita in 2013	-0.054	0.790	-0.066	0.632
IEEPI ₂₀₂₂ and the value of GDP per capita in 2022	0.028	0.889	0.037	0.786

Furthermore, the study delves into social aspects of energy policy effectiveness, particularly addressing energy poverty and self-sufficiency. These factors are crucial in shaping societal well-being and resilience. The multidimensional IEEPI and its associated values for EU-27 countries offer a rich foundation for interpretation and discussion of the obtained results. Likewise, the analysis of the dynamics of change in individual indicators and the IEEPI-DCI index provides valuable insights into the rate of progress across various aspects of energy policy within these countries.

Undoubtedly, these findings substantially contribute to the understanding and evaluation of the implementation of the EU-27 energy policy.

6. Conclusion

This article examines the critical and timely subject of multidimensional effectiveness assessment in EU energy policy from 2013 to 2022. To achieve the study's objectives and address its research questions, we developed two original methodological approaches. The first approach employs MCDM methods to calculate the IEEPI of EU energy policy. The second approach incorporated indicator dynamics values along with the derived IEEPI-DCI index. These indices were calculated using a multi-criteria methodology that combined CODAS, TOPSIS, and VIKOR methods, supplemented by the Hurwicz criterion for uncertainty analysis. Weighting was performed using three objective methods (CRITIC, equal weights, and statistical variance) and Laplace's criterion. Both methodologies employed a consistent set of 13 indicators representing fundamental dimensions of EU energy policy.

The study's primary objective across both methodological approaches was to assess the implementation effectiveness of EU energy policy, with particular emphasis on four key dimensions: (1) energy independence, (2) energy security, (3) climate neutrality, and (4) social considerations. For this research, effectiveness was operationalized as the degree to which EU energy policy objectives and priorities were successfully achieved.

The developed methodology and research findings reveal significant insights into EU energy policy implementation across the EU-27 countries from 2013 to 2022. Sweden and Finland demonstrate the most effective policy implementation during the study period, while Cyprus shows substantial implementation challenges. Notably, Malta and Estonia exhibit exceptional performance in achieving energy policy objectives, whereas Denmark and Austria underperform relative to other member states. Estonia and Malta demonstrate particularly strong performance in strengthening energy security. Estonia has achieved substantial reductions in energy import dependence, while Malta has made significant progress in energy self-sufficiency. Regarding climate neutrality and energy security objectives, the Netherlands, Malta, and Estonia emerge as top performers. Specifically, the Netherlands leads in nuclear energy adoption, Estonia excels in renewable energy integration for transportation and greenhouse gas emission reductions, and Malta shows outstanding progress in renewable energy deployment for electricity generation and heating/cooling applications. Hungary and Malta demonstrate the most significant progress in addressing energy transition challenges, effectively reducing energy poverty rates.

In contrast, the Netherlands shows the weakest performance in energy security enhancement, marked by growing dependence on energy imports and declining self-sufficiency. Among Central and Eastern European countries,

Poland, Latvia, and Hungary encounter particular difficulties in meeting environmental targets: Poland has seen decreased renewable energy adoption in transportation, and Hungary has experienced declines in both renewable energy share (total energy mix) and heating/cooling applications, resulting in increased greenhouse gas emissions. The research findings yield several policy recommendations to improve EU energy policy implementation efficiency. First, establishing a systematic monitoring framework to track progress rates across key energy indicators would enable targeted policy adjustments. This evidence-based approach would help identify underperforming areas and facilitate the design of country-specific interventions. Second, scaling up RES investments, with minimum funding thresholds tied to national GDP levels, is critical for reducing fossil fuel dependence and accelerating emissions reductions.

To advance EU energy policy objectives, strategic support for nuclear power development should be prioritized as both a clean energy solution and an innovation driver for the European economy. Significant funding increases should target interdisciplinary R&D in critical energy technologies, including: (1) energy storage systems, (2) next-generation nuclear power, (3) hydrogen energy infrastructure, and (4) advanced clean coal applications. Concurrently, comprehensive public engagement initiatives must promote understanding of climate neutrality targets, energy sovereignty imperatives, and sustainable consumption practices.

To maximize energy efficiency gains, regulatory frameworks should establish binding minimum standards across key sectors, including construction, industry, transportation, and agriculture. Priority must also be given to modernizing energy infrastructure, particularly in member states with obsolete systems, through strategic investments in: Smart grid technologies; Advanced energy storage solutions; Distribution network upgrades. Furthermore, strengthening EU energy solidarity mechanisms would accelerate collective progress, ensuring targeted support for nations encountering significant transition challenges while advancing shared climate and energy objectives.

Like all research, this study has certain limitations that simultaneously suggest promising avenues for future investigation. The primary limitation relates to the selection of indicators. Specifically, the analysis would have benefited from including cost-related metrics for the energy transition process, particularly those reflecting policy implementation expenses. However, such indicators were excluded due to insufficient availability of reliable data. Access to such cost data and its correlation with investment outcomes would significantly enhance the evaluation of policy implementation effectiveness. Future research should also incorporate greater analysis of the social impacts of energy transitions, particularly regarding employment effects. Additionally, expanding the assessment framework to include energy efficiency across key economic sectors—such as construction, industry, transportation, households, and especially

agriculture would provide valuable insights. The agricultural sector merits particular attention given its substantial EU subsidy framework.

A regular, comprehensive assessment of EU energy policy implementation effectiveness should be institutionalized across member states, incorporating energy, economic, social, and environmental dimensions. These evaluations should directly inform the ongoing development and refinement of both the EU-level energy strategy and national initiatives for technological modernization. The energy transition presents a strategic opportunity to build a modern, innovative, and globally competitive European economy. By embedding sustainable development principles across production and consumption systems, this transformation can serve as the foundation for enhanced economic prosperity and quality of life throughout the EU.

The proposed methodological framework combines three weighting approaches (CRITIC, equal weights, and standard deviation), Laplace's criterion, three MCDM techniques (CODAS, TOPSIS, and VIKOR), and Hurwicz's criterion for IEEPI index calculation. While this multi-method approach offers notable advantages in objectivity and versatility by: Reducing subjectivity through diverse weighting schemes; Enabling multi-perspective indicator evaluation; Strengthening result credibility through methodological triangulation. It nevertheless presents certain inherent limitations common to complex analytical frameworks.

The incorporation of Laplace's criterion serves to mediate between methodological approaches, thereby improving the robustness and generalizability of the results. Meanwhile, Hurwicz's criterion offers adaptive risk assessment by evaluating multiple uncertainty scenarios, which significantly enhances the analytical depth of the decision-making framework. The proposed methodology nevertheless presents some limitations. First, its computational complexity, stemming from the integration of multiple MCDM methods with Hurwicz's criterion, may constrain applications requiring rapid assessments or where analytical resources are limited. Second, the subjective nature of determining Hurwicz's optimism parameter introduces potential variability in outcomes, necessitating careful justification in application-specific contexts.

The model requires additional validation across diverse research contexts to assess its generalizability and identify opportunities for refinement. While these limitations exist, the proposed methodology establishes a robust framework for advancing multi-criteria assessment techniques. Its analytical toolkit significantly enhances decision-support capabilities, particularly for evaluating energy transitions and addressing complex sustainability challenges.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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