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Empirical Evaluation of the Energy Transition Efficiency in the EU-27 Countries over a Decade—A Non-Obvious Perspective

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Abstract

In response to the escalating challenges of climate change and the urgent need to reduce greenhouse gas emissions, the energy transition has become a central priority of environmental policy worldwide. The European Union (EU), a global leader in implementing sustainable energy solutions, has pursued numerous initiatives aimed at advancing energy transformation. This paper presents the results of an empirical study assessing the efficiency of the energy transition process in the EU-27 countries over the 2013–2023 period. The assessment is based on the dynamic changes in selected indicators relevant to the energy transition, including decarbonization of the energy sector, improvements in energy efficiency, the share of renewable energy sources, energy import dependency, greenhouse gas emissions, and the extent of energy poverty. A multidimensional analysis was conducted using a specially developed energy transition efficiency index, where indicator weights were determined through the Analytic Hierarchy Process. The study also examined two distinct sub-periods (2013–2018 and 2018–2023), as well as a series of shorter, two-year intervals (2013–2015, 2015–2017, 2017–2019, 2019–2021, and 2021–2023), enabling a more nuanced analysis of the temporal evolution of transition efforts. Additionally, principal component analysis was employed to classify the EU-27 countries based on the similarity of their energy transition profiles. The findings reveal significant disparities in the pace and scope of energy transition across member states. Luxembourg, Malta, and the Netherlands demonstrated the most dynamic progress during the study period, followed by Sweden, Denmark, Germany, and Estonia. In contrast, Bulgaria, Hungary, Poland, Latvia, Croatia, and Romania recorded the lowest performance. These differences underscore the varying starting points, policy approaches, and implementation speeds among EU countries in achieving energy transition objectives.

Keywords: energy transition; process efficiency; decarbonization; EU-27; multivariate analysis; ETEI index

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1. Introduction

In the context of ongoing climate change and increasing pressure for sustainable development, energy transition is one of the most important challenges of the modern world [1,2]. This process is a response to the worsening problems of climate change, ensuring energy security, and the growing geopolitical threat in the world. These factors have caused us to observe the progressive degradation of the environment for many decades [3,4]. It can

also be assumed that they are the main determinants of the transformation towards more efficient, low-carbon, and crisis-resilient energy systems.

Energy transition is most often defined as a complex and multifaceted process of significant changes in the way the economy and society obtain, process, and use energy. Its effects significantly affect the structure of energy sources, energy carriers, conversion technologies, and energy services [5,6]. Today, the process of energy transition, especially in the context of sustainable development, should be understood much more broadly. It is a multidimensional process of transforming energy systems to move from a system of energy based on conventional sources to one based on zero-carbon and, in particular, renewable energy sources. It is also very important to assume that this process should not disrupt the pace of economic development and be socially acceptable, without causing deterioration in the livelihood of citizens [7].

Therefore, it can be assumed that it includes both changing the structure of energy production and consumption, including increasing the share of renewable energy sources (RES), improving energy efficiency, as well as reducing greenhouse gas emissions, and reducing dependence on imports of energy resources. An important element, often forgotten, is also the reduction of energy poverty, which can occur in many countries undergoing transition, with particular emphasis on developing countries [8,9].

Faced with global threats of greenhouse gas emissions, dwindling supplies of conventional energy sources, and growing energy demand, European Union countries have taken intensive measures to change the energy mix of their economies. The aim of these efforts is to meet the growing demand for energy while minimizing the negative impact on the environment, in particular by reducing greenhouse gas emissions and improving energy efficiency.

According to the European Energy Policy, one of the main goals of the energy transition is to increase the share of renewable energy sources in the energy mixes of EU countries [10,11]. The goal of these measures is to achieve climate neutrality by 2050, which involves a transition to zero-carbon energy sources, including mainly RES [12,13]. This, in turn, should reduce greenhouse gas emissions from the energy sector and the economy in general, and, therefore, improve the living comfort of citizens. It is worth noting that the first regulations supporting the energy transition in the European Union appeared as early as the 1990s [14]. However, it was not until the adoption of the so-called climate and energy package in 2008 that it could be considered the beginning of decisive and concrete actions in this regard. This is because it was then that three strategic goals were set for EU countries to achieve by 2020, known as the "3 × 20" principle. These goals included: reducing greenhouse gas emissions by 20%, increasing the share of RES to 20%, and improving energy efficiency by 20% relative to 1990 levels [15].

Since then, the EU's climate policy has been successively updated, with the adoption of, among others, the European Green Deal in 2019 [12] and the "Fit for 55" legislative package in 2021 [16], which aims to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels.

Since energy transition is a long-term process that requires long-term and systematic efforts, it becomes necessary to evaluate its effectiveness. The results of such an assessment should become the basis for improving the entire process, taking further measures, modifying earlier assumptions, or targeting financial resources. The sensibility of conducting such studies is also due to the fact that previous work on this topic has focused mainly on comparative analyses of individual European Union countries in the context of sustainable energy development, most often for selected years of such assessment, e.g., [17–22]. The complexity of the energy transition process, its nature, and the scope of its effects, as well as its role and importance for the economy and society, make it necessary to take a

comprehensive approach to the evaluation of this process. In particular, this applies to the evaluation of its effectiveness, and with consideration of the various areas affected by the process.

The efficiency of the energy transition process should be understood as the degree and pace of achievement of the transition goals of decarbonizing the economy, increasing the share of renewable energy sources, improving energy efficiency, and ensuring energy security and social equity. This refers both to the direction of the changes taking place (i.e., the compliance of activities with the stated goals of energy and climate policy) and their dynamics.

Evaluating the efficiency of the energy transition of a group of countries (e.g., EU-27) provides an opportunity to show which countries are showing the greatest progress in achieving energy transition goals. It also provides opportunities to monitor the effectiveness of the energy and climate policies pursued by individual countries.

Previous studies clearly indicate that in the EU-27, the leaders of the energy transition are the Scandinavian countries, in particular, Sweden, Denmark, and Finland [17,21,22]. These countries have been consistently developing renewable energy sources for years, have low greenhouse gas emissions per unit of energy, and have high energy efficiency. However, are they also leaders in terms of the pace of change? The answer to this question is not clear-cut, as leadership in the energy transition can be understood in different ways.

Therefore, in order to address the problems identified, it becomes reasonable to carry out a study aimed at an empirical assessment of the effectiveness of the energy transition in the EU-27. This assessment was carried out on the basis of indices of the dynamics of change of selected indicators, key from the point of view of the energy transition process. The analysis took into account the most important aspects of the transition, such as the decarbonization of the energy sector, improving energy efficiency, increasing the share of renewable energy sources (RES), reducing greenhouse gas emissions, reducing dependence on imports of energy resources, and reducing the phenomenon of energy poverty. The approach used, based on the indices of the dynamics of change, makes it possible to assess transformational progress from a slightly different perspective than those used so far.

The study was conducted for the 2013–2023 period. In addition to the full-time span, two medium-term sub-periods (2013–2018 and 2018–2023) were analyzed to identify changes in the pace of transformation between them. Furthermore, the analysis included a series of shorter, two-year intervals (2013–2015, 2015–2017, 2017–2019, 2019–2021, and 2021–2023), allowing for a more detailed examination of short-term dynamics and fluctuations in the energy transition process.

In addition, using the principal component analysis (PCA) method, a classification of EU-27 countries in terms of similarity in energy transition efficiency was carried out. These measures were aimed at determining groups of EU-27 countries with similar transformation profiles. The approach adopted for the study and the research methodology developed are innovative. The originality of the work undertaken is evidenced by the following factors:

- The use of a dynamic approach, in which the assessment of the effectiveness of the energy transition was based on indicators reflecting changes over time (2013–2023), rather than on absolute values. This made it possible to capture the pace and direction of change, which is particularly important in the context of differences in the starting level of member states.
- Dividing the assessment of energy transition efficiency into two medium-term sub-periods (2013–2018 and 2018–2023) allowed for the identification of shifts in the dynamics of the transition process. This division provided valuable insight into how external factors, such as the COVID-19 pandemic and the war in Ukraine, influenced the pace and direction of changes in national energy systems. Additionally, the

inclusion of five shorter sub-periods (2013–2015, 2015–2017, 2017–2019, 2019–2021, and 2021–2023) enabled a more detailed and nuanced analysis of short-term fluctuations, helping to capture temporary accelerations or slowdowns that might be obscured in longer-term assessments.

- A multidimensional assessment of the effectiveness of the energy transition process, which took into account not only classic indicators such as the share of RES or GHG per capita, but also less obvious but crucial aspects of the process, such as energy poverty or the degree of dependence on energy imports. This allowed for a more comprehensive assessment and consideration of the various dimensions of energy policy.
- PCA-based comparative snapshot. The use of principal component analysis made it possible to identify latent patterns and relationships between countries and classify EU countries according to their transformational profile.

The factors indicated and the importance of the issue taken up for the further development of the EU-27 and individual member countries fully justify taking up this research topic. The innovative approach of the EU-27 to climate policy should also be emphasized. Many countries and regions of the world are watching how this original and very bold process affects the economy and the environment. Indeed, the EU-27 has become a forerunner of a comprehensive and decisive approach to building a sustainable, environmentally neutral economy

2. Literature Background

The literature review addresses the most important aspects related to the concept of energy transition and methods for its evaluation.

2.1. The Concept of Energy Transition

In the literature, one can find numerous attempts to define the energy transition process. Currently, this process is considered one of the key challenges of the modern global economy. For this reason, many countries are taking steps to implement solutions to support this process, while assuming that it will contribute to solving various types of social, climate, and economic problems [21,23–25].

The variety of definitions of energy transition is primarily due to its multidimensional nature and changing political, technological, and social conditions. On the one hand, it is considered a comprehensive process of changes in the ways in which societies obtain, process, and use energy, including both the change of energy sources and carriers and the development of related technologies and energy services [5]. On the other hand, some researchers point out that this transformation involves the successive displacement of dominant energy sources by other, more efficient or sustainable ones, as part of successive stages of civilization development [26]. Still other approaches focus on systemic change. Energy transition is then seen as a shift from one set of energy sources and technologies to another, with economic, social, and environmental consequences [27]. Hirsh and Jones, on the other hand, pay attention to the historical aspect of these changes, equating the energy transition with the transition between specific types of fuels (e.g., from wood to coal, from coal to oil) and their associated technologies (e.g., the transition from a steam engine to an internal combustion engine) [28].

A similar approach is presented by Miller et al., who emphasize changes in both the structure of fuels used and their conversion technologies, understanding energy transition as a fundamental reconstruction of energy systems [29]. In turn, Grubler proposes a simplified definition, according to which energy transformation should be understood as the process of transition from one energy system to another [30].

Newer studies are also increasingly emphasizing the political and social dimensions of the energy transition. This process is seen not only as a technological or infrastructural change, but also as a phenomenon conditioned by political decisions, affecting the balance of power between stakeholders, ownership regimes, and decision-making mechanisms in the energy sector [31]. Increasingly, the concept of energy transition also includes issues related to the social dimension [7].

Regardless of the definition used, energy transition is a process that involves activities aimed at reducing greenhouse gas emissions and increasing the share of renewable energy while reducing dependence on fossil fuels and improving energy efficiency [32–34]. This process involves many economic, economic and social areas by which its study and evaluation requires a multidimensional approach.

2.2. The Concept of Energy Transition Process Efficiency

In the literature on the subject, the concept of energy transition efficiency was introduced in [35]. According to that study, energy transition efficiency refers to a timely and balanced process of moving toward a more inclusive, sustainable, affordable, and secure global energy system. This process should address current global energy challenges while simultaneously creating value for both business and society, without disrupting the balance of the energy trilemma, which includes energy security, equitable access, and environmental sustainability.

Given the clear terminological gap and lack of a precise definition of energy transition efficiency, this study proposes a new formulation tailored to the adopted analytical objectives. The proposed concept defines energy transition efficiency as a country's ability to achieve measurable progress in key areas of sustainable energy development directly related to the energy transition process within a specified time frame. This efficiency is assessed based on the dynamics of change, as reflected by partial indicators that quantitatively capture the degree of progress in individual dimensions relative to the adopted baseline.

2.3. Evaluating Countries' Energy Transition

In the existing literature, there are several approaches for measuring and evaluating the energy transition process, which are mainly based on quantitative indicators on the basis of which aggregate evaluation indicators are determined.

An example of such an index is the Global Energy Transition Index (ETI) [36]. This index measures progress in the energy transition along four dimensions: sustainability, energy availability and efficiency, technological innovation, and government policies that support the transition to RES. It takes into account sub-indices including the share of renewable energy in the energy mix, energy efficiency in various sectors of the economy, and progress in technological innovation. Undoubtedly, the value of this indicator can be used to assess and compare countries in terms of the effectiveness of energy policies.

The World Energy Trilemma Index, on the other hand, is an index developed by the World Energy Council, used to assess the effectiveness of energy policies at the national level, as well as for international comparisons [37].

In the literature on the subject, there is a growing number of attempts to assess progress in just energy transition using various indicators, assessment methods, and geographical scopes [21,38–44].

A study covering 30 Chinese provinces from 2005 to 2021 [42] utilized 18 indicators and revealed systematic progress in the transformation process across all three major regions of the country. In contrast, Aperagi et al. [43] developed an energy justice index, which was applied to evaluate the transition in selected countries of the Global South (including Malaysia, Kenya, Jordan, and Chile), revealing significant disparities in national achievements.

Zheng et al. [44] analyzed the global energy transition from the perspective of international energy trade, using environmental indicators related to global warming, acidification, and eutrophication. Their findings highlighted clear progress in developed countries (e.g., Germany, UK, Japan), while high emission levels persist in emerging economies such as China.

In the context of the European Union, many studies focus on comparative assessments of the level of advancement in the energy transition among member states, using indicators such as the share of renewable energy sources, reduction in greenhouse gas emissions, and energy efficiency. These analyses allow for identifying both transition leaders and countries struggling to meet climate and energy goals.

Li et al. [38] proposed a Composite Energy Transition Index for 88 countries (1990–2020), based on 13 indicators across four dimensions: accessibility, affordability, environmental sustainability, and technological development. Although average index values increased over time, most countries still remain at a low level of transition. The use of automatic weighting, however, may have inflated the importance of certain indicators at the expense of expert knowledge.

Siksnelyte-Butkiene et al. [39] also applied a multi-criteria approach, using eight indicators assessed by experts. The study covered the years 2010 and 2018 and showed the dominant position of Scandinavian countries. However, the analysis was limited to comparing two points in time, without accounting for the dynamics of change.

Ziemba and Zaire [40] developed the Temporal PROSA method (from the group of dynamic methods T/DMCDM), combining PROMETHEE and PROSA approaches. They included 11 indicators, several of which specifically concerned the share of renewables in different sectors (transport, heating, electricity), which may have skewed the assessment in favor of one area. Although the study identified the countries with the highest levels of advancement (Sweden, Portugal, Denmark, Finland), the method did not allow for evaluating the pace of progress over time.

Pietrzak et al. [21] used taxonomic methods to classify EU countries in terms of transformational potential. Of the 16 indicators used, only six directly referred to the energy transition, while the rest covered areas such as innovation, education, and household income. This broad approach may have limited accuracy in assessing the energy transition itself. The analysis showed that Scandinavian countries and Estonia have the highest transformational potential, while Southern and Eastern European countries may face difficulties in meeting EU goals.

Elavarasan et al. [41] created a Composite SDG7 Index for 40 European countries, based on 13 sub-indicators grouped into five areas: clean energy, energy security, accessibility, energy consumption intensity, and CO_2 emissions. The indicator weights were determined using the AHP method. The study showed that Iceland, Norway, and Sweden achieved the highest scores. However, as with other studies, the results referred to a specific moment in time and did not capture the dynamics of change.

An analysis of the literature on the assessment of the energy transition in European Union countries reveals significant methodological and interpretative limitations in the research approaches used. Most studies focus on evaluating the level of advancement of the energy transition at a given point in time, with a dominance of cross-sectional analyses and country rankings based on selected sets of indicators. While such approaches allow for the identification of leaders and laggards in the transformation process, they do not capture the actual dynamics of change or long-term development trends. In light of this, it can be stated that existing analyses of the energy transition in the EU are predominantly static in nature. They assess the level of progress in a selected year but do not measure the pace of advancement or the scale of change over time. There is a lack of a comprehensive

dynamic approach that would allow for monitoring the actual course of the energy transition, identifying turning points, and evaluating the effectiveness of policies over a longer time horizon.

Therefore, it is fully justified to develop a new methodological approach that incorporates both dynamic and contextual aspects, integrating quantitative data with expert knowledge. This would enable the generation of more accurate and useful decision-making information for managing the energy transition. Assessing the effectiveness of the transition process based on change dynamics indices would allow not only for the determination of the current state of advancement but, more importantly, for capturing the direction, pace, and intensity of ongoing processes. Such an approach would make it possible to identify countries that are achieving real progress, regardless of their initial ranking position, as well as to diagnose the barriers slowing down the transition process in the countries studied.

3. Research Methodology

The purpose of the presented research was to quantitatively assess the effectiveness of the energy transition in the European Union member states from 2013 to 2023. The assessment was also carried out for sub-periods, i.e., for the years 2013–2018 and 2018–2023. This approach makes it possible to identify both long-term trends and changes occurring over shorter time frames, which allows for a more detailed analysis of the dynamics of changes in the energy transition process in individual member states. This makes it possible to capture moments of acceleration or deceleration in the process, as well as to identify which countries and to what extent they are meeting energy and climate policy goals, and which are facing difficulties in implementing them.

A new index has been proposed for evaluation—the energy transition efficiency index (ETEI), which takes into account energy, environmental, and social aspects related to the energy transition process. It is based on the values of the indices of the dynamics of change of indicators characterizing the dimensions adopted for the study, which are key from the point of view of the energy transition process.

3.1. Data

The research used data from the EUROSTAT database [45] and Energy Pocketbook (EU Energy Statistical Pocketbook) [46] for the period covering 2013–2023 (2023 is the last year for which complete statistical data used in the research is available). The data had to be characterized by completeness, consistency, and comparability between EU member states. The indicator values used in the study are consistent with the reference values and methodologies published by Eurostat. Based on these, the authors determined the values of the change dynamics indices used in the research.

A total of 7 indicators were used in the study, which are key metrics directly related to the energy transition process and aligned with the directions and priorities of the EU's energy and climate policy. The selection of indicators is justified by the specific nature and purpose of the study. It should be noted that in multi-criteria methods, there is no ideal or universally optimal number of indicators. The number depends on the specific problem under investigation, the complexity of the decision, and the nature of the criteria being assessed. However, some studies clearly indicate that their number should not exceed 20 [47]. Therefore, it is important to maintain balance in indicator selection in order to avoid insufficient or excessive evaluation criteria for the issue under study.

The set of indicators adopted for the study met the following necessary criteria for the assessment:

- relevance to the objectives of EU energy and climate policy;
- simplicity in the construction of indicators;

- simplicity in the interpretation of indicators as a fundamental analytical tool;
- comparability;
- applicability in econometric models, forecasting models, and other data analytics contexts;
- availability.

Table 1 presents and justifies the selection of indicators that were used to study the efficiency assessment of the energy transition process.

Table 1. Indicators used for the study.

Indicator	Relationship with Energy Transition
Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita	Energy transformation seeks to reduce energy consumption while maintaining the same level of energy services. Lower primary energy consumption per person means higher energy efficiency.
Energy imports dependency, %	Energy transition involves increasing the share of local, renewable energy sources, reducing the need to import energy. High dependence on imports also means less energy independence, which affects energy security, which is extremely important during the transition of the economy.
Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %	Energy transition aims to reduce greenhouse gas emissions to combat climate change. This is achieved, among other things, through decarbonization, including reducing the share of emitting energy sources in the energy mix. The smaller the share of these sources (e.g., coal, gas), the greater the progress of the energy transition.
Energy intensity, kilograms of oil equivalent per thousand euros	Energy transformation seeks to increase energy efficiency, which is also expressed by producing more goods and services with less energy. Lower value means greater efficiency in the economy.
Total GHG per capita, t CO_2 eq.	Energy transformation aims to reduce greenhouse gas emissions. The indicator shows how carbon-intensive the economy is and how effective climate and energy policies are. The lower the value, the more "zero-carbon" the economy.
Share of renewable energy in gross final energy consumption, %	A high share of renewables is the cornerstone of the energy transition, as it reduces CO_2 emissions and increases energy security.
Population unable to keep home adequately warm by poverty status, %	Energy transformation is not just about technology and emissions—it must also be socially just. This indicator shows the level of energy poverty, that is, the situation in which people do not have the means to pay for heating costs or live in energy inefficient buildings, thus increasing the cost of living.

3.2. Methodology for Determining the Index for Evaluating the Efficiency of Energy Transformation

The research process used a multi-criteria analysis approach, allowing aggregation of various indicators into one with a specific cell function, i.e., the level of efficiency of energy policy implementation.

The index proposed for assessing the efficiency of the transformation process consists of seven subcomponents (Table 1), expressing the change in the indicators adopted for the study over time. Both typical energy indicators (e.g., energy efficiency—primary energy consumption, energy imports dependency, share of emitting energy sources in the energy mix, share of renewable energy in gross final energy consumption), environmental indicators related to GHG emissions, as well as indicators reflecting the social aspect of the energy transition process (energy poverty), are included.

Thus, the Energy Transformation Efficiency Index (ETEI) is based on indices of the dynamics of change in key indicators of the energy transition process. Its value is determined from Equation (1):

$$ETEI = w_1 \times \Delta RES + w_2 \times \Delta PEC + w_3 \times \Delta EID + w_4 \times \Delta ESE + w_5 \times \Delta EIw_6 \times \Delta GHG + w_7 \times EUW \quad (1)$$

where ΔRES is the change in the share of renewable energy sources; ΔPEC is the change in primary energy consumption per capita (energy efficiency); ΔEID is the change in import dependency; ΔESE is the change in the share of emitting energy sources in the energy mix; ΔEI is the change in the energy intensity of the economy; ΔGHG is the change in the greenhouse gas emissions of the economy, and ΔEUW is the change in the percentage of the population affected by energy poverty.

ΔX indicators included in the study in the period $t_0 - t$ were determined from the following equation:

- for stimulants:

$$\Delta X = \frac{X_t}{X_{t_0}} - 1 \tag{2}$$

- for destimulants:

$$\Delta X = 1 - \frac{X_t}{X_{t_0}} \tag{3}$$

A positive value of the energy transition efficiency index indicates an improvement in the situation in the country under study, i.e., a positive direction of change in key aspects of the energy transition. On the other hand, a negative value of the designated index indicates a deterioration of energy transition conditions in the country. This condition indicates a regression or lack of progress in achieving the goals related to the energy transition process in a given period.

The developed Energy Transition Effectiveness Index, therefore, allows a comprehensive and quantitative assessment of countries' progress in achieving their energy transition goals. By taking into account energy, environmental, and social aspects, the index makes it possible to compare the effectiveness of activities in a number of transformation dimensions across countries and study periods.

The weights of the indicators included in the study were determined using the AHP method. This method belongs to the MCDM group of methods and consists of hierarchical ordering of the decision problem and making pairwise comparisons between elements at each level of the hierarchy. In this method, evaluations are made using a preference scale, usually a nine-point scale, reflecting the relative importance of one element to another. On the basis of the obtained comparison matrices, eigenvectors are determined, which represent the relative weights of the studied criteria. In addition, in order to assess the consistency of the results obtained, Consistency Ratios (CRs) are calculated, whose values should not exceed a set threshold, usually 0.1, for the results of the analysis to be considered reliable [48–51].

The algorithm for determining weights using the AHP method consists of the following steps:

- To define a hierarchy of criteria for the adopted decision problem.
- To create a matrix of pairwise comparisons for the criteria under consideration. In this approach, each criterion is compared with other criteria based on a preference scale (1–9). This creates a pairwise comparison matrix A (4):

$$A = \begin{bmatrix} 1 & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \dots & 1 \end{bmatrix} \tag{4}$$

where a_{ij} is the evaluation of the importance of the i-th criterion in terms of j.

- To create a normalized matrix of pairwise comparisons:

$$A_{norm} = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} & \cdots & \frac{a_{1n}}{\sum_{i=1}^{n} a_{i1}} \\ \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} & \cdots & \frac{a_{mn}}{\sum_{i=1}^{n} a_{in}} \end{bmatrix} \quad (5)$$

- To calculate the value of the average weight for each evaluation criterion. The average weight w_j for the i-th criterion is calculated as the arithmetic mean of the values of the given row of the normalized matrix:

$$w_j = \frac{\sum_{j=1}^{n} A_{norm,\, ij}}{n} \quad (6)$$

- To evaluate the consistency of the results obtained, i.e., CI and CR coefficients:
  - Calculation of the vector λ_{max}:

$$\lambda_{max} = \frac{\sum_{j=1}^{n} (A \times w_j)}{n} \quad (7)$$

  - Calculation of CI consistency index:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (8)$$

  - Calculation of the consistency factor CR:

$$CR = \frac{CI}{RI} \quad (9)$$

  where RI is the table value for random matrices. If $CR < 0.1$, then the comparisons are consistent.

In turn, the Principal Components Approach (PCA) was used to divide EU countries into groups in terms of energy transition efficiency profiles.

The principal component analysis method is one of the most widely used methods of data dimensionality reduction, especially for multidimensional sets with high levels of collinearity among variables. Its primary purpose is to transform the original correlated input variables into a new set of variables. The resulting so-called principal components (components) are linear combinations of the original variables and are mutually orthogonal (uncorrelated). Each successive principal component explains as much of the variability as possible that was not explained by the previous components [52–54].

From a mathematical point of view, the PCA method is based on the distribution of the covariance or correlation matrix of the input variables. For a data set $X \in \mathbb{R}^{n \times p}$, where n is the number of observations and p is the number of variables, the first step is to standardize the data (as long as they are measured in different units). Then, the covariance or correlation matrix is determined, for which the eigenvalue is solved (Equation (10)):

$$\sum v_i = \diagdown_i v_i \quad (10)$$

where $\diagdown_i$ stands for the eigenvalue and v_i stands for the corresponding eigenvector (that is, the direction and weight of the i-th principal component). The subsequent components are ranked in descending order with respect to their corresponding eigenvalues, which represent the amount of variance in the data translated by the component.

The transformation of the data to the new component space is implemented using Equation (11):

$$Z = XV \tag{11}$$

where Z is the resulting matrix containing the coordinates of the observations in principal component space, and V is the matrix of eigenvectors (component loads).

Thus, the PCA method makes it possible to simplify the structure of the data with minimal loss of information. As a result, the method makes it possible to identify hidden patterns, relationships between variables, and typology of the objects under study (in this work, countries) by mapping them into principal component space.

4. Results

The section presents the results of the studies conducted in order and with the necessary commentary.

4.1. Evaluation of the Effectiveness of Energy Transition Evaluation Criteria (Indicators) from 2013 to 2023

In the first stage of the study, an evaluation of the individual criteria (indicators) used to assess the energy transition efficiency of each EU-27 country was conducted. By analyzing the index of dynamic change, the direction and intensity of changes in individual sub-indicators over the 2013–2023 period were examined. This analysis enabled the identification of trends in the indicator values, thereby facilitating an assessment of the direction of energy transition—whether it reflects progress, stagnation, or regression.

For the following indicators: total greenhouse gas emissions per capita, decarbonization of the energy sector (i.e., the share of emitting sources in the energy mix), energy intensity, primary energy consumption (as a measure of energy efficiency), energy import dependency, and the proportion of the population unable to keep their home adequately warm (as a measure of energy poverty), a negative value in the index of dynamic change represents a favorable outcome. This indicates a decrease in the given indicator's value, signifying improvements such as lower emissions, enhanced energy efficiency, increased energy independence, and a reduction in energy poverty—thus representing progress toward the objectives of the energy transition.

Accordingly, the analysis assumes that negative values for these indicators signify advancement in the energy transition, whereas positive values suggest stagnation or regression. This approach ensures the coherent and policy-aligned integration of these indicators into the construction of the aggregate energy transition efficiency index (ETEI), consistent with the goals of the EU's climate and energy policy.

Notably, the evaluation criterion based on primary energy consumption, as a key indicator of energy efficiency, revealed significant disparities in performance across EU countries during the 2013–2023 period (Figure 1).

The most significant progress in reducing primary energy consumption was observed in Estonia and Luxembourg, each of which achieved a reduction of approximately 31%. This substantial decrease likely reflects the effective implementation of energy efficiency policies, structural shifts in their economies, or a decline in energy-intensive industrial activities.

At the other end of the spectrum, Croatia experienced an 18% increase in primary energy consumption during the study period, representing the most pronounced negative trend among the EU-27 countries. Notably, this upward trend was also recorded in seven other member states. Bulgaria and Lithuania reported increases of 13%, indicating persistently high energy intensity in their economies and a lack of sufficient measures to improve efficiency. Latvia saw an increase of 5%, while Cyprus and Poland each recorded a 4% rise—both signaling limited effectiveness in their respective energy transition strategies. In

Romania and Hungary, energy consumption grew by 3% and 2%, respectively. Although these increases are more moderate, they still deviate from the EU's recommended trajectory toward reduced energy use.

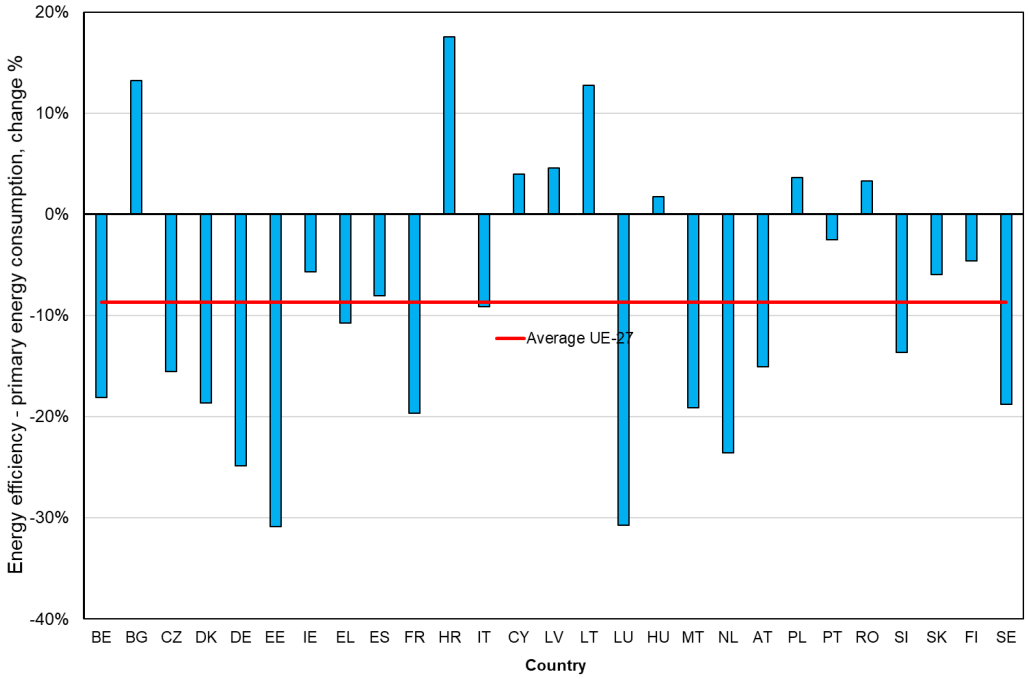


Figure 1. Changes in the value of the indicator showing energy consumption per capita in individual EU-27 countries between 2013 and 2023.

These findings suggest that several EU member states continue to face significant challenges in curbing primary energy consumption, which is a critical component of the broader energy transition.

The second indicator included in the assessment—energy import dependency—addresses a key aspect of energy security. Here, too, EU countries exhibit substantial variation in their efforts to reduce reliance on external energy sources (Figure 2).

The most significant decrease in energy import dependency—representing the most favorable direction of change from the perspective of energy security—was observed in Estonia, where the indicator dropped by 75%. This sharp decline reflects the country's notable progress toward independence from external energy sources. Substantial reductions were also recorded in Latvia (−41%) and Finland (−40%), followed by Sweden (−20%) and Ireland (−15%). These results suggest that these countries have effectively pursued strategies aimed at enhancing energy self-sufficiency, including the development and integration of renewable energy sources.

In contrast, particularly concerning trends were observed in countries such as Denmark and the Netherlands, where energy import dependency surged by 216% and 197%, respectively. Significant increases were also recorded in Poland (+83%), the Czech Republic (+51%), and Romania (+52%), indicating a worsening of energy security conditions in these member states. Among the remaining countries, changes in import dependency were generally more moderate, typically within a few percentage points. Some countries managed to stabilize or slightly reduce their dependency levels—for instance, Austria saw no change, while Belgium recorded a marginal decrease of 1%.

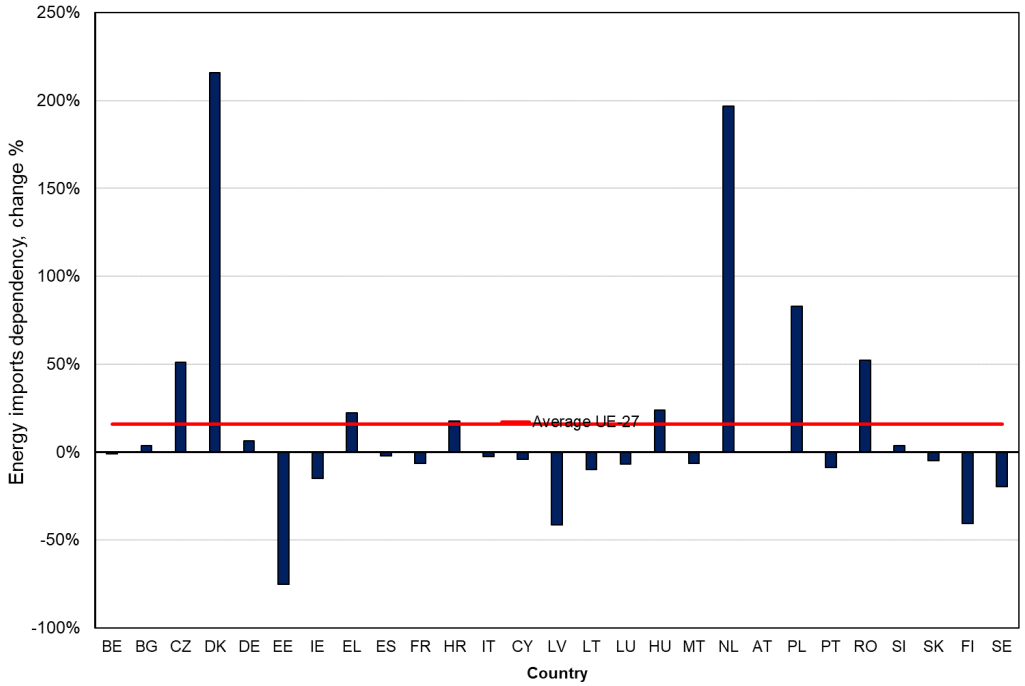


Figure 2. Changes in the value of the energy import dependency index in individual EU-27 countries between 2013 and 2023.

Another critical indicator for assessing the progress of the energy transition is the share of emitting energy sources in the energy mix, which reflects the degree of decarbonization within the energy sector. An analysis of the dynamic change index for this indicator over the 2013–2023 period reveals significant variation in the effectiveness of EU member states in reducing their reliance on fossil fuels for energy production (Figure 3).

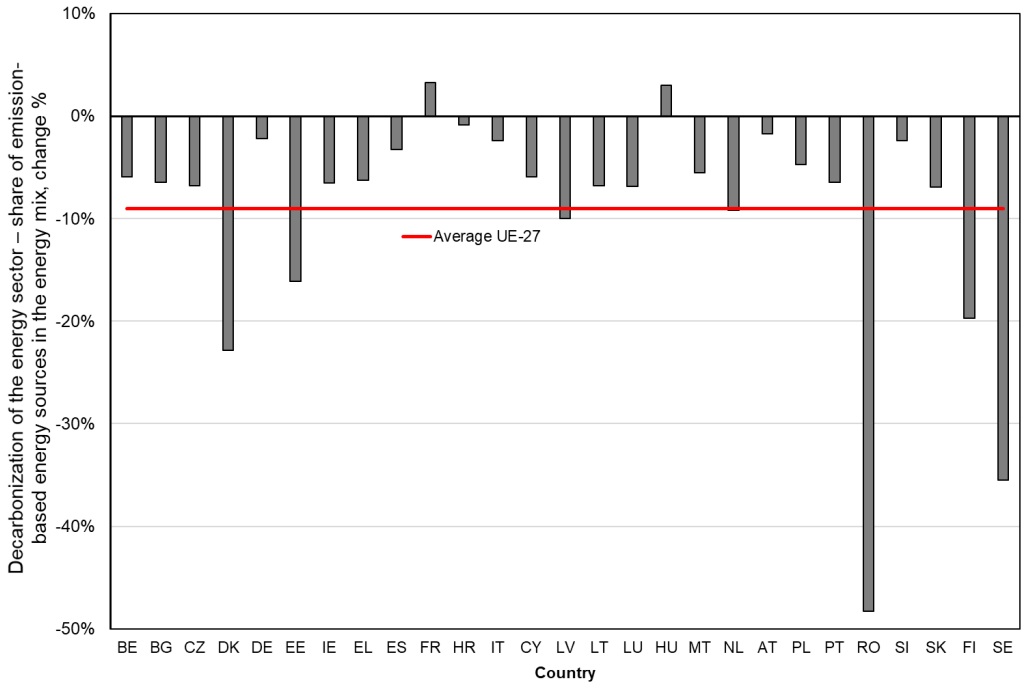


Figure 3. Effectiveness of the process of reducing emission sources in the energy mix of individual EU-27 countries between 2013 and 2023.

An analysis of the results presented in Figure 3 reveals that the highest efficiency in reducing the share of emitting sources in the energy mix between 2013 and 2023 was

achieved by Romania (−48%), Sweden (−35%), and Finland (−20%). Denmark (−23%) and Estonia (−16%) also demonstrated high performance in decarbonizing their energy sectors. These strongly positive outcomes reflect consistent efforts by these countries to expand zero-carbon energy sources, particularly renewables, and to reduce reliance on coal, oil, and natural gas in energy production. These actions align with EU climate policy recommendations.

In contrast, relatively small reductions were observed in Croatia (−1%), Germany (−2%), Austria (−2%), Spain (−3%), and Italy (−2%), indicating a slower pace of energy transition. Particularly concerning are the cases of France and Hungary, where the share of emitting energy sources in the energy mix actually increased by 3% in both countries—signaling a negative trajectory in terms of decarbonization.

The next indicator analyzed was energy intensity (Figure 4), defined as the amount of primary energy consumed (in kilograms of oil equivalent) per 1000 EUR of GDP. This measure allows an assessment of how efficiently countries utilize energy within their economic processes. A declining energy intensity value indicates improved energy efficiency—producing more economic value with less energy input.

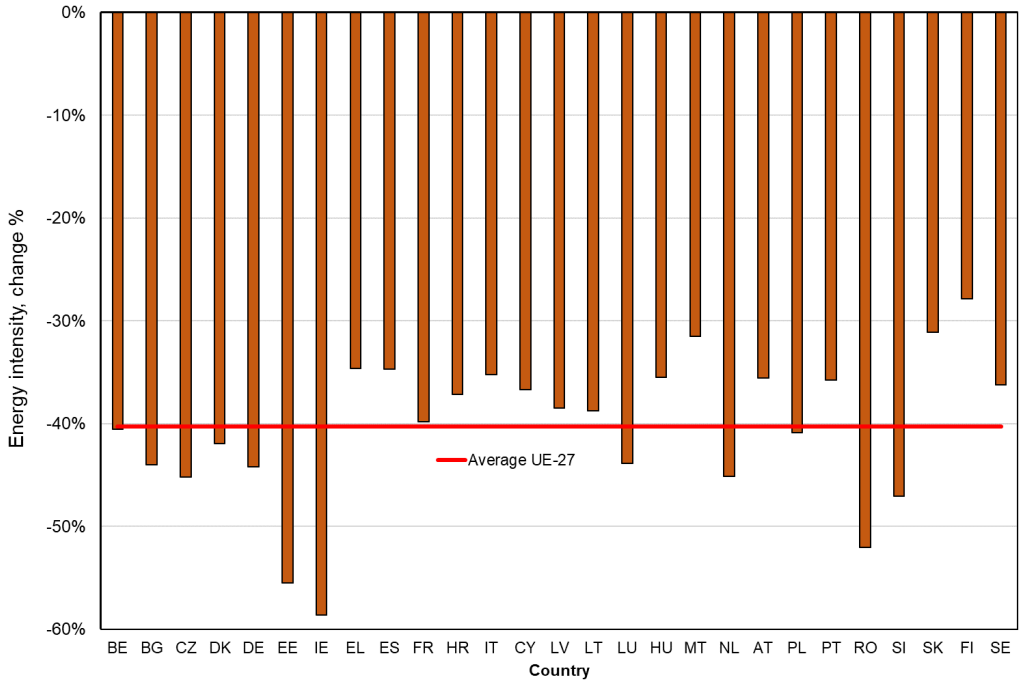


Figure 4. Effectiveness of the process of reducing the energy intensity of EU-27 economies between 2013 and 2023.

The analysis (Figure 4) shows that all EU-27 countries made progress in reducing energy intensity between 2013 and 2023. The most substantial improvements were recorded in Ireland (−59%), Estonia (−56%), and Romania (−52%), followed by Slovenia (−47%), the Czech Republic, the Netherlands, and Germany (each at −45%). These reductions indicate significant efforts to enhance production efficiency and reduce energy waste.

By contrast, the lowest reductions in energy intensity were found in Finland (−28%) and Slovakia (−31%). Despite these comparatively modest gains, the overall EU-wide trend remains positive, indicating that the goal of improving energy efficiency, expressed through reduced energy intensity, is being realized across the region.

A core goal of the energy transition is achieving climate neutrality, for which the reduction in greenhouse gas emissions per capita is a critical indicator. Effective decarbonization

is closely tied to continuous declines in carbon dioxide and other GHG emissions. However, data from the 2013–2023 period show wide disparities in country performance (Figure 5).

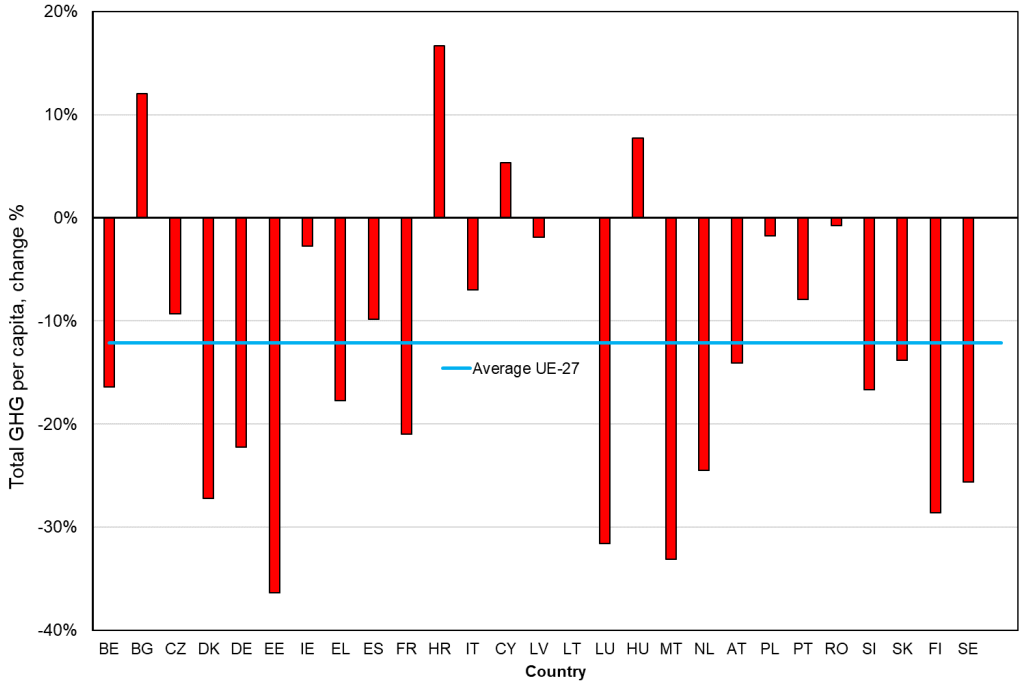


Figure 5. Effectiveness of GHG emission reductions per capita in the EU-27 between 2013 and 2023.

The greatest reductions in per capita GHG emissions were achieved by Estonia (−36%), Malta (−33%), Luxembourg (−32%), Finland (−29%), and Denmark (−27%). These reductions reflect effective climate policies, robust development of renewable energy (Figure 6), improved energy efficiency (Figure 4), and successful decarbonization efforts (Figure 3). Countries with moderate reductions included Sweden (−26%), the Netherlands (−24%), Germany (−22%), France (−21%), and Austria (−14%).

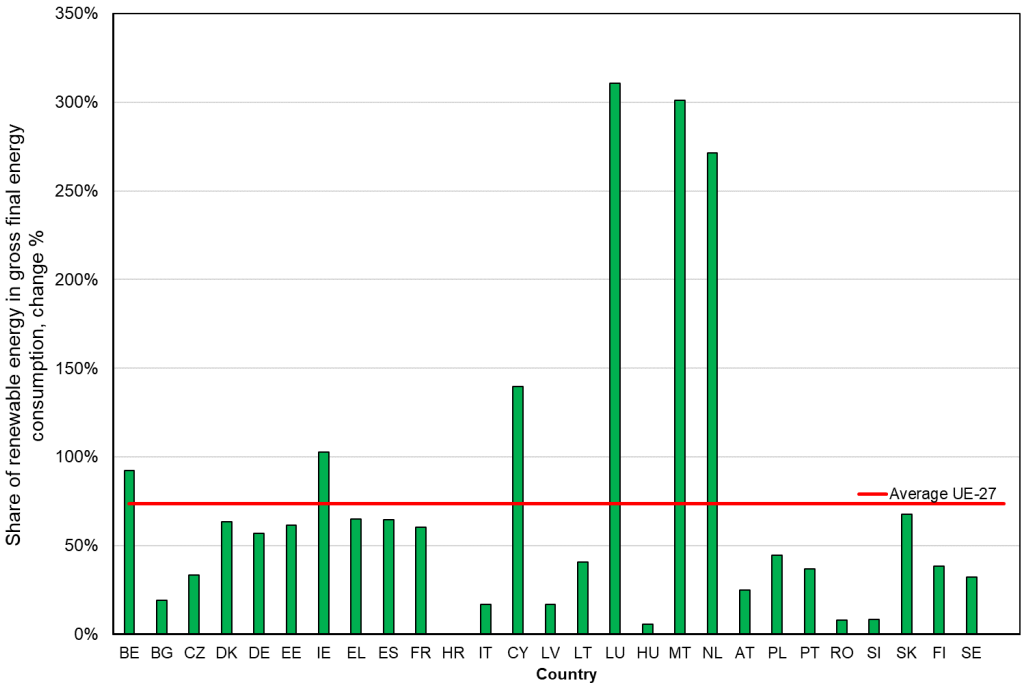


Figure 6. Change in the value of the indicator share of renewable energy in gross final energy consumption in the EU-27 countries between 2013 and 2023.

Meanwhile, only minimal reductions were recorded in Poland and Latvia (−2%) and Romania (−1%). Even more concerning were four countries—Croatia (+17%), Bulgaria (+12%), Hungary (+8%), and Cyprus (+5%)—that saw increases in per capita emissions over the period. Lithuania recorded no change (0%). These results highlight slower progress or even regression in climate mitigation efforts in several member states.

Overall, the average GHG reduction across the EU-27 between 2013 and 2023 was 12%, which, while modest, still represents a positive direction.

A key indicator closely tied to the energy transition is the share of renewable energy in gross final energy consumption. Between 2013 and 2023, the EU-27 saw an average increase of 73% in renewable energy consumption. However, there were substantial differences among countries, largely due to their starting points in 2013 and structural differences in their economies and energy sectors (Figure 6).

The most significant growth occurred in Luxembourg (+311%), Malta (+301%), and the Netherlands (+271%). These exceptional increases were largely due to their very low starting shares of renewables in 2013 (around 3.5–4.6%), which created greater potential for rapid expansion. In contrast, countries like Sweden, which already had a high renewable share, recorded more modest but still positive growth (+32%).

Other notable performers included Cyprus (+140%) and Ireland (+103%), both of which made above-average progress. Strong increases were also observed in Slovakia (+68%), Greece and Spain (both +65%), Denmark (+63%), Estonia (+62%), and France (+61%). These outcomes reflect systematic and effective changes to national energy mixes.

A clear pattern emerges: countries with low initial shares of renewables achieved the highest growth rates, while those with already strong renewable sectors continued progressing at a more stable pace.

Another crucial dimension of the energy transition is its social impact, particularly in terms of energy poverty—measured here by the percentage of the population unable to keep their homes adequately warm due to poverty [55]. This indicator highlights the social vulnerabilities that can be exacerbated by rising energy costs or insufficient policy support (Figure 7).

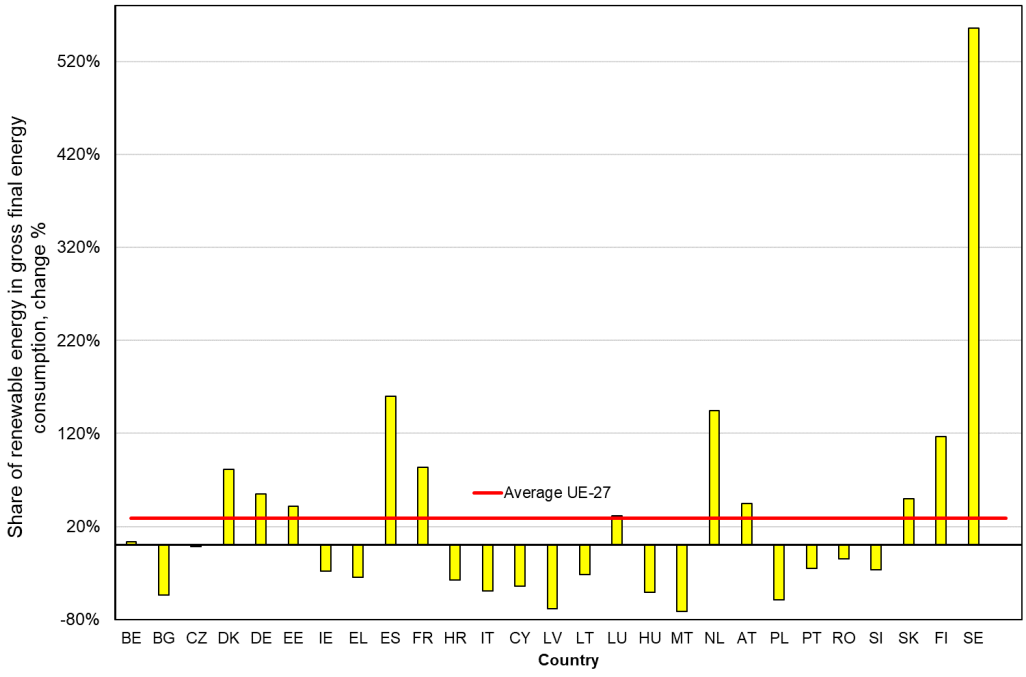


Figure 7. Changes in the value of the indicator characterizing energy poverty in individual EU-27 countries in 2013–2023.

Analyzing the results obtained (Figure 7), it can be concluded that the largest increases in the population affected by residential heating problems occurred in Sweden (+556%), Spain (+160%), the Netherlands (+145%), Finland (+117%), and France (+83%). These clear and alarming increases are the result of rising energy prices, especially in the final period covered by the analysis, which intensified during the energy crisis caused by the war in Ukraine after 2021 [56,57].

Overall, 16 EU-27 member states achieved marked improvements in reducing energy poverty among their populations. Malta (−72%), Latvia (−69%), Poland (−59%), Bulgaria (−54%), and Hungary (−51%) saw the largest decreases in the rate. The improvement in these countries is the result of, among other factors, increased citizens' incomes (such as raising the minimum wage), building modernization programs, and improved energy efficiency in housing [58]. Greece, Cyprus, Italy, and Ireland also recorded significant declines in this indicator, reflecting the effectiveness of protective and social measures.

A summary of the best and worst performance across the evaluated criteria (indicators) during the period under review (2013–2023) for each country is shown in Table 2.

Table 2. The highest and lowest rated areas of energy transition in each EU country.

Country	Best Result	Worst Result
BE	Share of renewable energy in gross final energy consumption, %	Population unable to keep home adequately warm by poverty status, %
BG	Share of renewable energy in gross final energy consumption, %	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita
CZ	Energy intensity, kilograms of oil equivalent per thousand euros	Energy imports dependency, %
DK	Share of renewable energy in gross final energy consumption, %	Energy imports dependency, %
DE	Share of renewable energy in gross final energy consumption, %	Population unable to keep home adequately warm by poverty status, %
EE	Energy imports dependency, %	Population unable to keep home adequately warm by poverty status, %
IE	Share of renewable energy in gross final energy consumption, %	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita
EL	Share of renewable energy in gross final energy consumption, %	Energy imports dependency, %
ES	Share of renewable energy in gross final energy consumption, %	Population unable to keep home adequately warm by poverty status, %
FR	Share of renewable energy in gross final energy consumption, %	Population unable to keep home adequately warm by poverty status, %
HR	Population unable to keep home adequately warm by poverty status, %; Energy intensity, kilograms of oil equivalent per thousand euros	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita
IT	Population unable to keep home adequately warm by poverty status, %; Energy intensity, kilograms of oil equivalent per thousand euros	Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %
CY	Share of renewable energy in gross final energy consumption, %	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita

Table 2. *Cont.*

Country	Best Result	Worst Result
LV	Population unable to keep home adequately warm by poverty status, %;	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita
LT	Share of renewable energy in gross final energy consumption, %	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita
LU	Share of renewable energy in gross final energy consumption, %	Population unable to keep home adequately warm by poverty status, %
HU	Population unable to keep home adequately warm by poverty status, %;	Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %
MT	Share of renewable energy in gross final energy consumption, %	Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %; Energy imports dependency, %
NL	Share of renewable energy in gross final energy consumption, %	Energy imports dependency, %
AT	Energy intensity, kilograms of oil equivalent per thousand euros	Population unable to keep home adequately warm by poverty status, %
PL	Population unable to keep home adequately warm by poverty status, %	Energy imports dependency, %
PT	Share of renewable energy in gross final energy consumption, %	Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita
RO	Energy intensity, kilograms of oil equivalent per thousand euros	Energy imports dependency, %
SI	Energy intensity, kilograms of oil equivalent per thousand euros	Energy imports dependency, %
SK	Share of renewable energy in gross final energy consumption, %	Population unable to keep home adequately warm by poverty status, %
FI	Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %	Population unable to keep home adequately warm by poverty status, %
SE	Energy intensity, kilograms of oil equivalent per thousand euros	Population unable to keep home adequately warm by poverty status, %

In general, it can be noted that the largest number of EU-27 countries, during the period under review, did best in increasing energy consumption from renewable energy sources (RES). This is the best area related to energy transition for 15 of the 27 member states. This result confirms the effectiveness of measures aimed at the development of renewable energy, supported both by EU climate and energy policy instruments and by national programs to support RES investments. The significant progress is also to some extent the result of the growing cost-effectiveness of renewable technologies, their increasing market availability, and wider public acceptance.

In contrast, the lowest progress occurred in areas such as energy import dependence, energy efficiency as measured by primary energy consumption per capita, and the percentage of the population unable to maintain an adequate temperature at home. The poor performance in these areas points to structural difficulties in becoming independent of external energy sources, as well as an insufficient pace of energy sector modernization and the limited scope of energy poverty reduction efforts. In particular, the growth of this poverty, mainly related to the geopolitical situation, is socially oppressive, which means that the acceptance of the energy transition process encounters great social resistance [59].

4.2. Assessing the Effectiveness of the Energy Transition

The section presents the results of the main part of the research, involving the determination of the efficiency of the transformation process in the EU-27 countries during the period studied.

4.2.1. The Value of the Weights of the Indicators Included in the Assessment

In the process of constructing the comparison matrix, which serves as the basis for determining indicator weights using the AHP method, ten experts participated. These individuals possessed both research and practical experience in the fields of energy transition, climate and energy policy, as well as multi-criteria analysis methods. The composition of the expert group was carefully selected to ensure the substantive quality of the assessments and to represent a range of scientific and practical perspectives.

Each expert was thoroughly informed about the purpose of the study, the definitions of all analyzed indicators, and the adopted time frame covering the years 2013–2023. Participants received a standardized set of source materials and methodological instructions, which ensured consistency in interpretation and comparative assessments. As a result, it was possible to obtain coherent and reliable results, which were subsequently subjected to a consistency analysis (including the calculation of CI and CR indices), confirming the high quality of the obtained weight matrix.

To minimize the risk of groupthink, the experts participating in the study worked completely independently of one another. They were unaware of each other's involvement and did not consult with one another during the assessment process. This approach ensured that each participant had full decision-making autonomy and eliminated the possibility of mutual influence on their evaluations.

The experts unanimously recognized that, in the context of the energy transition, the key indicator is total GHG per capita. High importance was also attributed to the indicators' share of renewable energy in gross final energy consumption and decarbonization of the energy sector, although their weights were assessed as slightly lower. The indicators energy intensity and energy efficiency, measured by primary energy consumption, were considered to be of moderate importance. Energy imports dependency was assigned lower importance, and the lowest weight was given to the indicator, population unable to keep homes adequately warm by poverty status.

It should be emphasized, however, that the lowest weight assigned to the energy poverty indicator does not imply a devaluation of its importance. Rather, it reflects the expert assessment of its role as a contextual indicator, related to the social environment and barriers to the transition, rather than one that directly describes progress in decarbonization, improvements in energy efficiency, or the increase in the share of renewable energy sources. The availability and affordability of energy, as represented by this indicator, are undoubtedly important elements of the transition, particularly from the perspective of social justice and public acceptance of change. However, in the present study, the adopted perspective focused on evaluating the effectiveness of the transition in terms of achieving measurable energy and climate policy goals aligned with the priorities of the EU climate and energy policy

The results of the AHP procedure are presented in Table 3. According to the conducted analysis, the highest weights were assigned to the indicators for greenhouse gas emissions per capita, the share of renewable energy sources, and the level of decarbonization of the energy sector, as direct measures of progress in the energy transition in its environmental and structural dimensions. On the other hand, the lowest weight was assigned to the energy poverty indicator, which, despite its significant social relevance, was considered by the experts to be an indirect factor in assessing the effectiveness of the transition itself.

Table 3. Weights of indicators used to determine energy transition efficiency.

Indicator	Symbol	Weight
Total GHG per capita, t CO_2 eq.	GHG	0.3856
Share of renewable energy in gross final energy consumption, %	RES	0.1878
Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %	ESE	0.1878
Energy intensity, kilograms of oil equivalent per thousand euros	EI	0.0862
Eneregic efficiency—primary energy consumption, tons of oil equivalent per capita	PEC	0.0862
Energy imports dependency, %	EID	0.0428
Population unable to keep home adequately warm by poverty status, %	EEU	0.0237

In order to assess the correctness of the determined values of the weights, calculations of the consistency indicators of the comparison matrix, such as the consistency index (CI) and the Consistency Ratio (CR), were carried out. The obtained values (CI = 0.0478 and CR = 0.0362) testify to a very good level of consistency of the matrix, which confirms the correctness of the performed procedure for determining the weights using the AHP method.

4.2.2. Evaluation of the Effectiveness of the Energy Transition Process Between 2013 and 2023

In the next stage of the research, a comprehensive analysis was carried out, taking into account all the key objectives determining the effectiveness of the energy transition process in the various countries studied.

Taking into account the weights of the indicators (evaluation criteria), the Energy Transformation Efficiency Index (ETEI) (Equation (1)) was determined for each of the EU-27 countries studied for the 2013–2023 period (Figure 8).

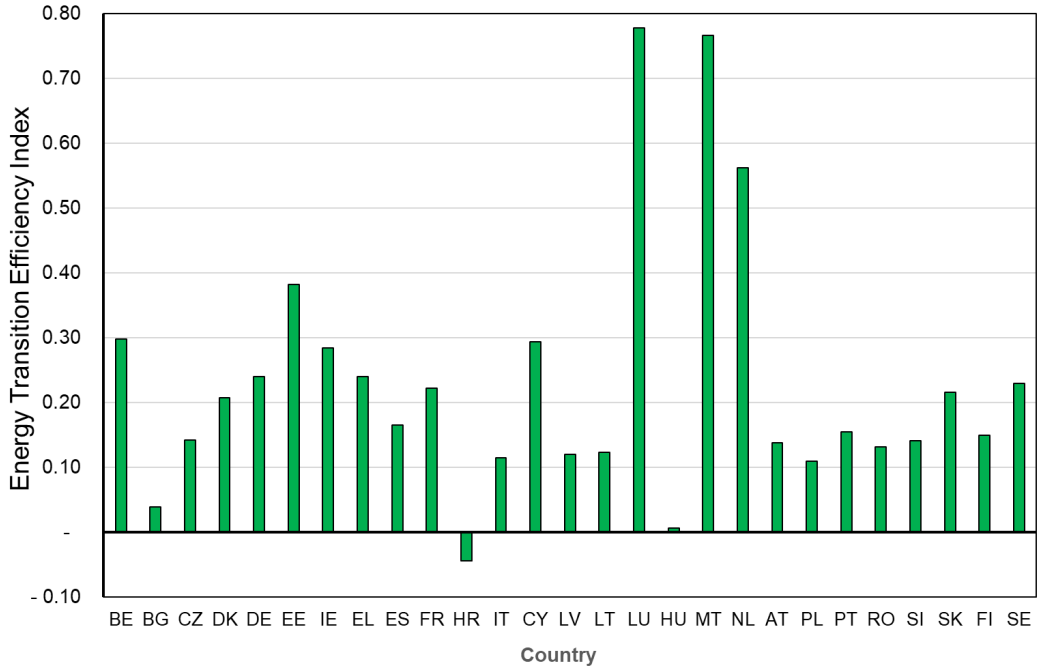


Figure 8. Values of the Energy Transformation Efficiency Index (ETEI) in each of the surveyed EU-27 countries for the 2013–2023 period.

An analysis of the value of this index (ETEI) for the period under study shows the varying pace of progress by individual European Union countries in decarbonization, improving energy efficiency, reducing GHG emissions, and reducing energy poverty.

The highest ETEI index values were achieved by Luxembourg (0.778), Malta (0.766), and the Netherlands (0.562), signifying relatively strong progress in energy transition compared to other countries. These achievements are the result of very high growth in RES energy consumption and, as a result, a significant decrease in per capita greenhouse gas emissions and energy intensity of these countries' economies between 2013 and 2023.

In contrast, Croatia (−0.044) and Hungary (0.006) show successive regression and stagnation in the energy transition process. In the case of Croatia, there has been no increase in the share of renewable energy sources in total energy consumption, and there has been little improvement in the energy intensity of the economy. In contrast, there was a significant increase in per capita greenhouse gas emissions and a decrease in energy efficiency. In Hungary, on the other hand, there was only a slight increase in energy consumption from RES, with an increase in GHG emissions per capita, due to the increasing share of fossil fuels in the national energy mix. Despite the decline in the energy intensity of the economy, the energy efficiency of the country as a whole did not improve.

The group of countries with moderate progress in energy transition included Belgium (0.300), Estonia (0.384), Ireland (0.282), and Germany (0.239). These countries saw a significant increase in the share of energy consumption from RES (e.g., Estonia: +62%, Ireland: +103%, Germany: +57%), as well as a significant decrease in the energy intensity of the economy and GHG emissions per capita. However, these countries show a limited pace of reduction in energy import dependence, growing energy poverty (e.g., Germany and Belgium), or relatively small changes in the energy mix towards decarbonization.

In contrast, countries such as Poland (0.109), Italy (0.107), Lithuania (0.120), and Latvia (0.117) have moderately low ETEI index values, indicating some progress, but to a limited extent. In the case of Poland, despite an improvement in energy intensity (−41%) and an increase in the share of energy consumed from RES (+45%), there is still a small reduction in the share of fossil fuels in the mix, which, in turn, affects a small reduction in GHG emissions per capita. In contrast, in Baltic countries such as Lithuania and Latvia, positive developments in reducing dependence on imported energy and improving energy efficiency have been undermined by stagnant emissions reductions and decarbonization of the energy mix.

The vast majority of countries are performing very well in terms of increasing the share of renewable energy sources in final energy consumption. However, challenges remain in reducing energy poverty and improving energy efficiency (Table 2). Belgium, Germany, and Spain are achieving strong results in RES development, yet they face high percentages of the population struggling to heat their homes. Conversely, countries like Bulgaria and Latvia are making progress in increasing the share of RES but continue to grapple with low energy efficiency. In the Czech Republic, Denmark, and Romania, the main challenges include reducing energy import dependency and further lowering the energy intensity of their economies. In countries with a low ETEI index, such as Croatia and Hungary, key issues include a high level of energy poverty and a growing share of fossil fuels in the energy mix.

Therefore, energy policy in these countries should be flexibly adapted to their specific conditions. States with good performance in RES development should focus on combating energy poverty and further enhancing energy efficiency. For example, Germany and Belgium could invest in support programs for the most vulnerable households, improving insulation in residential buildings, and developing smart energy grids that enable better management of energy consumption. On the other hand, countries such as Bulgaria and Latvia should concentrate on modernizing their energy infrastructure and implementing more efficient heating and cooling technologies, as well as promoting energy education among citizens.

For countries heavily dependent on energy imports, such as the Czech Republic, Denmark, and Romania, investments in local renewable energy sources and the development of energy storage systems are crucial to increasing energy independence. In Romania, it is also important to support industrial modernization with a focus on energy savings. Meanwhile, countries with a low ETEI index, such as Croatia and Hungary, should urgently revise their energy strategies to reduce the use of fossil fuels by developing RES and modernizing transmission networks, as well as introducing additional support programs to help transition local communities that are reliant on coal or gas.

4.2.3. Evaluation of the Effectiveness of the Energy Transition Process in Sub-Periods: 2013–2018 and 2018–2023

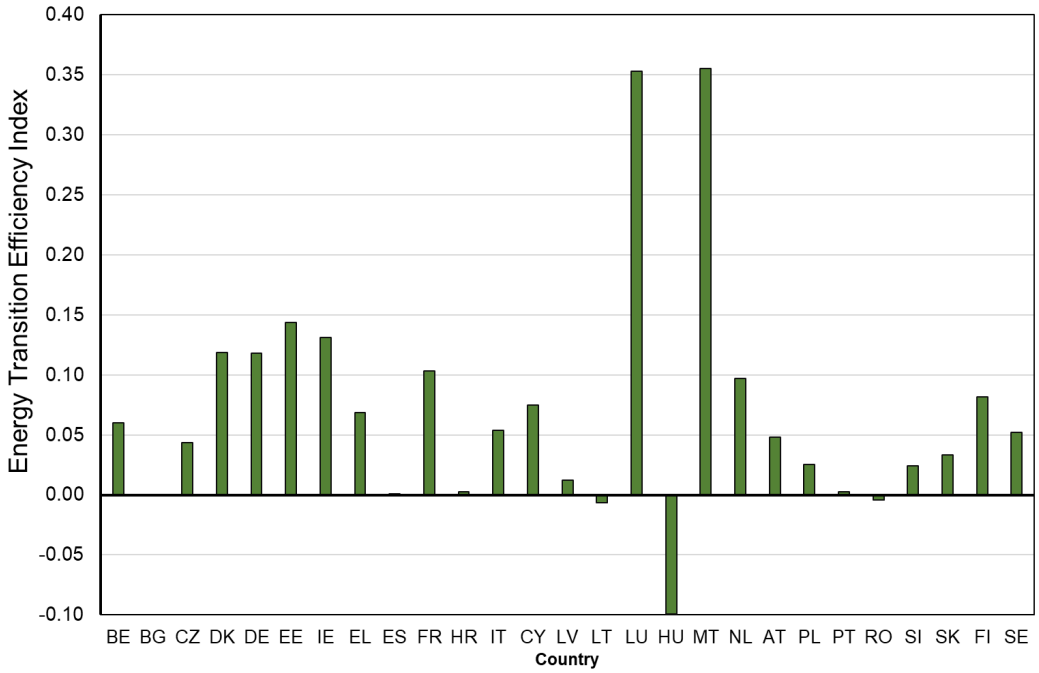
In addition to assessing the efficiency of the energy transition process over the entire period studied (2013–2023), additional analysis was carried out for two partial periods covering the years 2013–2018 and 2018–2023. These studies were aimed at capturing the dynamics of change and identifying any differences in the pace of transformation between the first and second halves of the decade under study. This periodization allows for a better understanding of the extent to which countries have accelerated or slowed down efforts to decarbonize and increase RES, reduce GHG emissions, improve energy efficiency, and reduce energy poverty. The analysis also makes it possible to link changes to the implementation of specific energy and climate policies at a given time and to the response to global crises.

Figure 9 shows the ETEI index values for two partial periods covering the years 2013–2018 and 2018–2023.

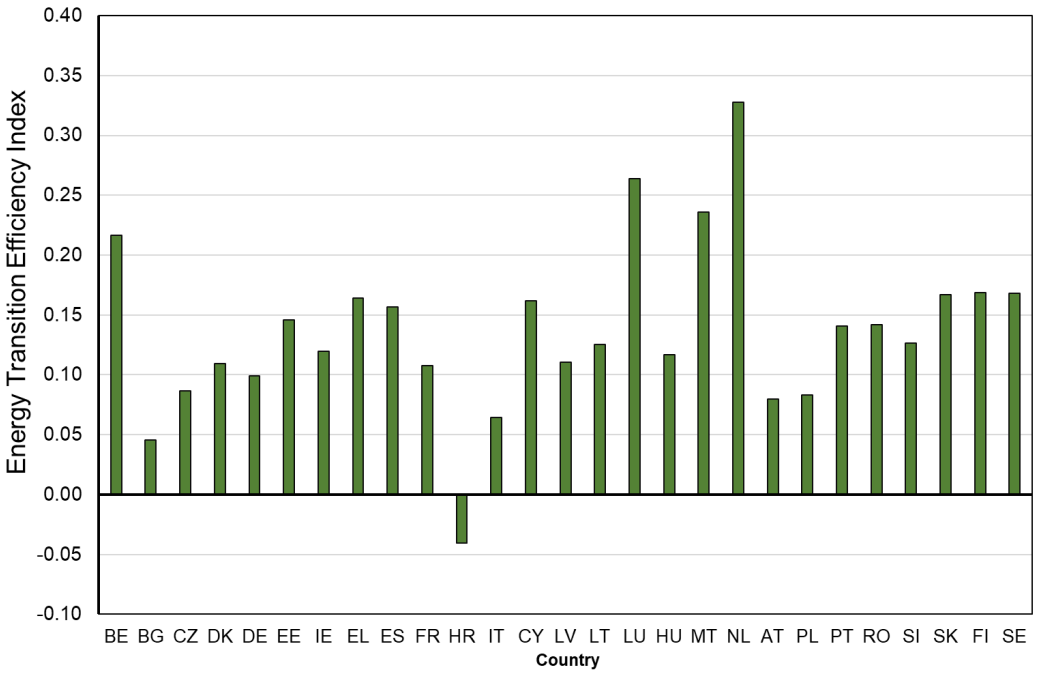
A comparison of the value of the designated index (ETEI) in these two sub-periods shows significant differences in the pace and efficiency of the energy transition between the EU-27 countries. In most countries, a clear acceleration of the transition can be observed in the second period under review, which may be due to the intensification of activities related to the emergence and implementation of the EU Green Deal, as well as the impact of global events, such as the crises related to the COVID pandemic and the war in Ukraine.

Countries such as Spain, Greece, Cyprus, Poland, Romania, Portugal, Slovakia, Finland, and Sweden recorded a significant increase in the index between 2018 and 2023, compared to the first sub-index (2013–2018), indicating a clear acceleration in the pace of the energy transition. Spain, for example, reached an index value of 0.157 in 2018–2023 (compared to only 0.001 between 2013 and 2018), while Poland increased efficiency from 0.025 to 0.083. In the case of Spain, this significant increase was primarily driven by the dynamic development of renewable energy sources, improved energy efficiency, and a substantial reduction in greenhouse gas emissions. Poland's progress in energy transition, on the other hand, was due to improved energy intensity of the economy (i.e., a reduction in energy consumption per unit of GDP), a growing share of renewable energy in the energy mix, and a decline in the share of emission-intensive sources. Such changes reflect the increasing effectiveness of actions undertaken within the framework of climate and energy policy, as well as the growing transformational potential of these countries in the context of achieving the EU's climate neutrality goals.

In contrast, countries such as Denmark, Germany, Ireland, and France show a relatively stable, moderate pace of transformation in both periods studied. For these countries, the ETEI index values remain at similar levels, showing consistent, but somewhat less dynamic changes. This pattern is characteristic of mature energy systems that have already achieved considerable progress in earlier years and are now fine-tuning rather than overhauling their energy structures. For example, Denmark and Germany maintained high levels of RES share and productivity; however, due to their already advanced position, the scope for rapid index growth was more limited.



(**a**)



(**b**)

Figure 9. Energy transition efficiency index values in the EU-27 in 2013–2018 (**a**) and 2018–2023 (**b**).

It is also worth noting Luxembourg and Malta, which record the highest values of the index in both periods, indicating the extremely high efficiency of the transformation process in these countries. Between 2013 and 2018, the index for Malta was 0.355 and for Luxembourg 0.353, while in the 2018–2023 period, the values remain very high—0.236 and 0.264, respectively. However, such high dynamics of change in both countries are largely due to their relatively unfavorable initial situation, especially in terms of dependence on energy imports, low share of RES, or high energy intensity of the economy in relation to other EU countries. The high growth rate of the index, therefore, reflects intensive catching

up, rather than reaching a high level of transformation sophistication, as is the case, for example, in Sweden, Denmark, or Finland.

Among all EU countries, Croatia is the only case showing a negative ETEI value for the period 2018–2023, indicating a regression in energy transition activities. This result signals a clear setback in efforts to decarbonize the economy, improve energy efficiency, and develop renewable energy sources. Several significant factors contributed to the deterioration of Croatia's ETEI. During the analyzed period, a decline in energy efficiency was observed, along with an increased dependence on imported energy sources, which undermines energy security and reduces resilience to external market shocks. Another unfavorable development was the rise in the share of emission-intensive, fossil fuel-based energy sources in the national energy mix. At the same time, greenhouse gas emissions per capita increased by over 40%. Furthermore, no significant progress was observed in the development of renewable energy sources during the analyzed period, suggesting either a lack of sufficient investment or the presence of institutional barriers to the implementation of green technologies.

The analysis of the two sub-periods shows that many EU-27 countries have significantly intensified their energy transition efforts in 2018–2023 compared to 2013–2018. This also provides an opportunity to assess the effectiveness of the changes being implemented in the energy systems of these countries.

4.2.4. Evaluation of the Effectiveness of the Energy Transition Process in Sub-Periods: 2013–2015, 2015–2017, 2017–2019, 2019–2021, 2021–2023

In addition to evaluating the efficiency of the energy transition process over the entire study period (2013–2023) and across two medium-term sub-periods (2013–2018 and 2018–2023), the next stage of the research also included additional analyses for shorter, two-year time intervals: 2013–2015, 2015–2017, 2017–2019, 2019–2021, and 2021–2023. The aim of these analyses was to capture the more detailed dynamics of change and to identify short-term fluctuations in the pace of the transition, which may have gone unnoticed in the long- and medium-term analyses presented in Sections 4.2.1 and 4.2.2.

Such periodization allows for a better understanding of the extent to which individual countries implemented changes aimed at decarbonization, the development of renewable energy sources (RES), the reduction in greenhouse gas emissions, improvements in energy efficiency, or the mitigation of energy poverty. Analyzing shorter time intervals also makes it possible to link observed changes with specific political, economic, or regulatory events, such as the implementation of climate policies, government changes, the launch of new support programs, or responses to global crises (e.g., the COVID-19 pandemic or the post-2021 energy crisis).

The results of these analyses are presented in Figure 10.

The analysis of the energy transition efficiency index (ETEI) over two-year periods allows for a more precise capture of the dynamics of progress in decarbonization, the increase in the share of renewable energy sources (RES), and improvements in energy efficiency across individual EU countries. The results indicate significant variation in the trajectories of the transition, both between the countries analyzed and over time.

Countries that achieved high and relatively stable values of the energy transition efficiency index across successive sub-periods include Denmark, Ireland, Finland, Sweden, as well as Malta, Luxembourg, and the Netherlands. The performance of these countries confirms consistent efforts toward reducing greenhouse gas emissions, developing renewable energy sources, and enhancing energy efficiency.

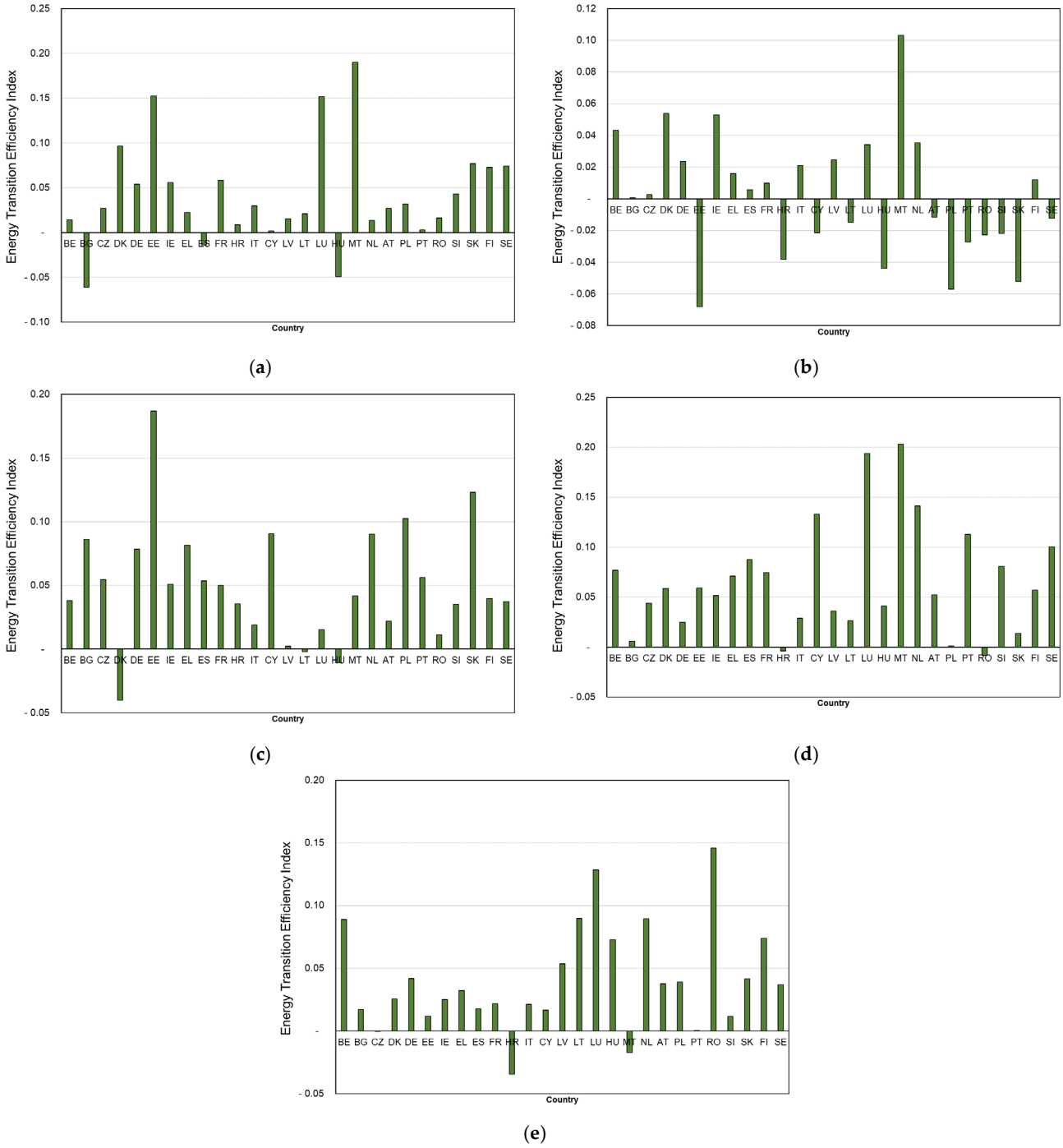


Figure 10. Energy transition efficiency index values in the EU-27 in 2013–2015 (**a**), 2015–2017 (**b**), 2017–2019 (**c**), 2019–2021 (**d**), and 2021–2023 (**e**).

In the first analyzed sub-period (2013–2015), Denmark achieved a very high ETEI value of 0.10 compared to other countries, indicating a strong transformational momentum. In most of the analyzed sub-periods, the country maintained a generally positive trend and, in the last two examined intervals, reached ETEI values of 0.059 and 0.026, respectively. Only during the 2017–2019 period did Denmark experience a slight regression. The ETEI dropped to −0.04, which was primarily due to a threefold increase in dependency on imported energy sources. This had a markedly negative impact on the country's energy balance and weakened its energy security. Additionally, a slight rise in the energy poverty rate was recorded during the same period, further contributing to the decline in the overall assessment of transition efficiency.

Ireland demonstrated exceptional stability in terms of energy transition progress, with the ETEI remaining at a level of 0.05–0.06 for most of the analyzed period. A slight decline to 0.03 was recorded only in the years 2021–2023. However, this is still a positive value, indicating the continuation of a favorable trend in reducing greenhouse gas emissions, increasing the use of renewable energy sources, and improving energy efficiency.

An example of a positive and consistent trajectory of energy transition is Finland, whose ETEI values increased in almost every subsequent sub-period. After achieving a high score in 2013–2015 (0.073), the country experienced a short-term slowdown during 2015–2017, when the index dropped to 0.012. This weakening was mainly due to a decline in energy efficiency, an increase in greenhouse gas emissions, and a rise in energy poverty during that period. In the following intervals, the ETEI value rose again, reaching 0.0398 in 2017–2019, 0.0570 in 2019–2021, and 0.0739 in the 2021–2023 period.

Sweden also belongs to the group of stable leaders in the energy transition, despite experiencing a transitional period of weakening in 2015–2017. In the first analyzed period (2013–2015), the country achieved a high ETEI value of 0.074. Over the following two years, the index dropped to −0.012, which was associated with a decline in energy efficiency, an increase in the share of emitting sources in the energy mix, and a sharp rise in energy poverty, which increased by over 75% during this short interval. Despite these developments, Sweden quickly returned to a growth trajectory: in 2017–2019, the index reached 0.037; in 2019–2021, it rose to 0.1005, and in the most recent analyzed sub-period (2021–2023), it remained at a positive level of 0.037.

In the case of Malta, a very high value of the ETEI was already observed in the first analyzed period covering the years 2013–2015, reaching 0.2. This indicates a strong transformational impulse resulting from a significant increase in the use of renewable energy sources (over 30% during this period), an almost 20% improvement in energy efficiency, a reduction in greenhouse gas emissions by more than 21%, and a decrease in energy poverty by over 40%. A similarly strong result reappeared in the 2019–2021 period, again reaching 0.2. However, during 2021–2023, a slight regression occurred, caused by an increase in GHG emissions, a decline in energy efficiency, and rising dependency on imported energy sources and energy intensity.

Luxembourg, on the other hand, exhibited noticeable fluctuations in the dynamics of energy transition efficiency across the individual sub-periods. After a very promising start, with the ETEI reaching a high value of 0.1518 in the years 2013–2015, the pace of progress slowed significantly in the two subsequent periods, falling to 0.0341 in 2015–2017 and just 0.0153 in 2017–2019. However, in the 2019–2021 period, a sharp acceleration of the transition process occurred, with the ETEI rising to an impressive level of 0.1937. During this period, the use of renewable energy sources increased by more than 60%, indicating intensified investment efforts and the effective implementation of green energy policies. At the same time, greenhouse gas emissions fell by over 13%, and energy efficiency improved by nearly 10%. A decrease in dependency on imported energy sources and a reduction of over 2% in the share of conventional sources in the energy mix were also observed.

Among the group of countries characterized by unstable or weak energy transition efficiency are Bulgaria, Croatia, Romania, and Poland. Their ETEI values show significant fluctuations between successive sub-periods, with frequent phases of stagnation and even regression. Bulgaria recorded a negative ETEI value (−0.06) in the years 2013–2015, followed by a minimal recovery (0.0007 in 2015–2017) and a dynamic increase in 2017–2019 (0.0864). However, in the next two periods, the pace of transition weakened again, with the ETEI values reaching just 0.0060 (2019–2021) and 0.0170 (2021–2023), respectively.

A similar dynamic is observed in Poland, where, following a positive result in the years 2013–2015 (0.0319), a departure from the transformation process occurred, reflected

in a decline of the ETEI index to a negative value (−0.0568) during the 2015–2017 period. The next sub-period (2017–2019) showed progress (0.1024); however, in 2019–2021, the transformation process nearly came to a halt, with the index dropping to just 0.0014. In the years 2021–2023, another acceleration in transition efficiency was recorded. These fluctuations indicate that Poland experiences significant internal disruptions and lacks a coherent and long-term energy strategy.

Croatia and Romania, in turn, are among the countries that, for a significant portion of the analyzed period, were characterized by low or even negative energy transition efficiency. In the case of Croatia, the ETEI value reached −0.0383 in the years 2015–2017 and −0.0343 in 2021–2023, indicating stagnation or regression in key areas of the energy transformation. The positive values recorded in the remaining time intervals were relatively low and did not compensate for the negative overall balance. This may suggest a lack of lasting support mechanisms for the transition process and a limited scale of implemented modernization measures.

Romania showed a clear recovery only in the most recent analyzed period (2021–2023), achieving a relatively high ETEI value of 0.1460. This is a clear sign of an acceleration in the transition process; however, in the earlier periods, the country recorded values close to zero or negative, indicating a delayed implementation of energy and climate policies.

In contrast, Hungary recorded consistently negative ETEI values during the first three analyzed periods (−0.05 in 2013–2015, −0.044 in 2015–2017, and −0.011 in 2017–2019). These values clearly indicate a regression in the energy transition process. Across the analyzed sub-periods, there was a deterioration in key parameters of the transition, an increase in dependency on imported energy sources, and a growing share of emitting energy sources in the energy mix. Simultaneously, greenhouse gas emissions rose in comparison to the baseline values for each respective period, further worsening the overall assessment of progress. This situation may stem from the limited implementation of measures supporting renewable energy, the slow pace of energy infrastructure modernization, and insufficient regulatory pressure to promote decarbonization.

4.3. PCA Analysis Results for 2013–2023

In the final stage of the study, using the PCA method, groups of European Union countries with similar profiles of efficiency in implementing the energy transition process were identified. PCA analysis was carried out on the seven variables adopted for the study (primary energy consumption per capita, dependence on energy imports, share of emitting energy sources in the energy mix, energy intensity of the economy, greenhouse gas emissions per capita, share of renewable energy sources, and energy poverty rate). All input data were in the form of indices of the dynamics of change, which made it possible to compare the rate and direction of change processes.

Table 4 summarizes the results of load calculations for the PC1 and PC2 components.

Table 4. Coefficients of variables (loads) for components PC1 and PC2.

Variable	PC1	PC2
Energy efficiency—primary energy consumption, tons of oil equivalent per capita	0.569	0.181
Energy imports dependency, %	−0.137	0.092
Decarbonization of the energy sector—share of emitting energy sources in the energy mix, %	0.199	−0.706
Energy intensity, kilograms of oil equivalent per thousand euros	0.095	−0.178
Total GHG per capita, t CO_2 eq.	0.578	0.107
Share of renewable energy in gross final energy consumption, %	−0.374	−0.459
Population unable to keep home adequately warm by poverty status, %	−0.366	0.454

The results of the calculations indicate that the first principal component (PC1) strongly differentiates countries in terms of energy efficiency improvements and greenhouse gas emission reductions, and also (although to a lesser extent), in terms of progress in reducing emission fuels in the energy mix. It can, therefore, be viewed as a consumption-carbon component. PC1 represents a gradient from countries that have increased per capita energy consumption and per capita GHG emissions over the decade, such as Bulgaria, Croatia, and Hungary, to countries that have reduced per capita energy consumption and per capita GHG emissions, i.e., more energy-efficient and green countries such as Sweden, Luxembourg, and the Netherlands.

The second main component (PC2) differentiates countries specifically on the effectiveness (improvement or lack thereof) of the energy poverty problem or progress in increasing RES energy consumption.

The PC2 component, therefore, separates countries that, on the one hand, show strong progress in the growth of RES energy consumption, but at the same time face a growing problem of social poverty (Sweden) from countries where there has been a slight reduction in emissive energy sources in the energy mix but where emission fuels continue to dominate. However, a decline in energy poverty is being observed (e.g., Malta, Luxembourg).

The first two principal components (PC1 and PC2) together explain 56.3% of the variability in the dataset (PC1—36.4%, and PC2—19.9%).

A visual representation, in two-dimensional space, of the main components of PC1 and PC2 is shown in Figure 11.

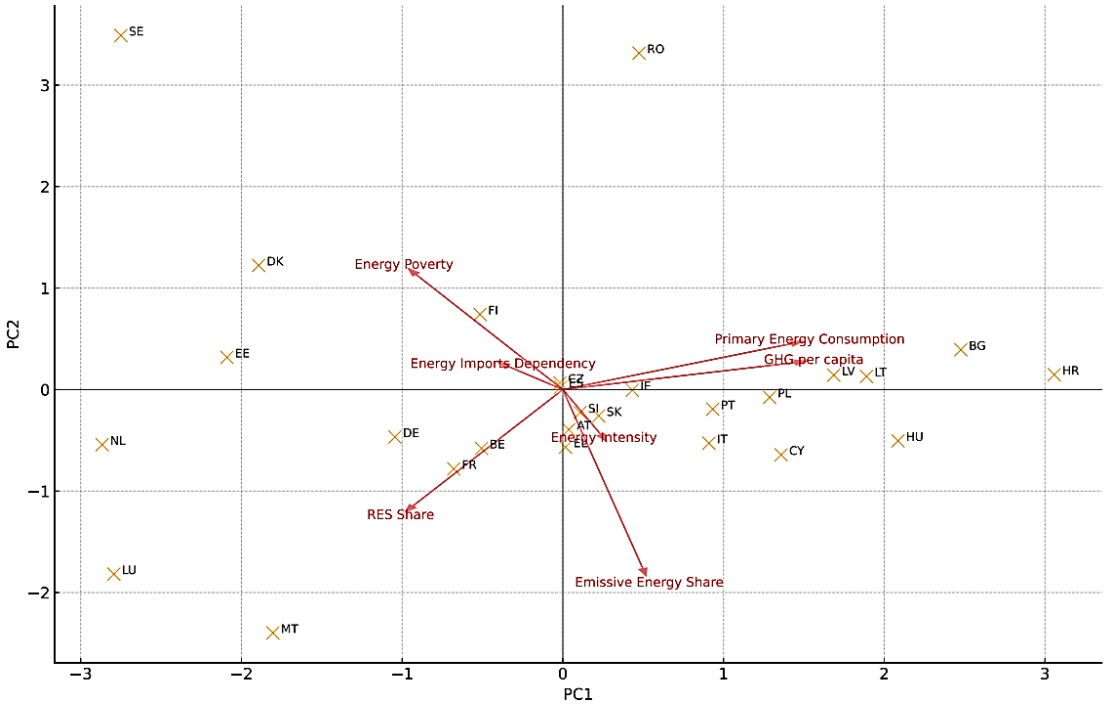


Figure 11. Results of principal component analysis of PC1 and PC2 for the studied EU27 countries.

On the basis of the results obtained, clustering of the studied countries was carried out using the k-means method. Its result was the separation of groups of EU-27 countries with similar profiles of energy transition efficiency in 2013–2023 (Figure 12).

The designated clusters reflect similarities in energy transition efficiency profiles, i.e., changes in the values of the indicators adopted for the study between 2013 and 2023.

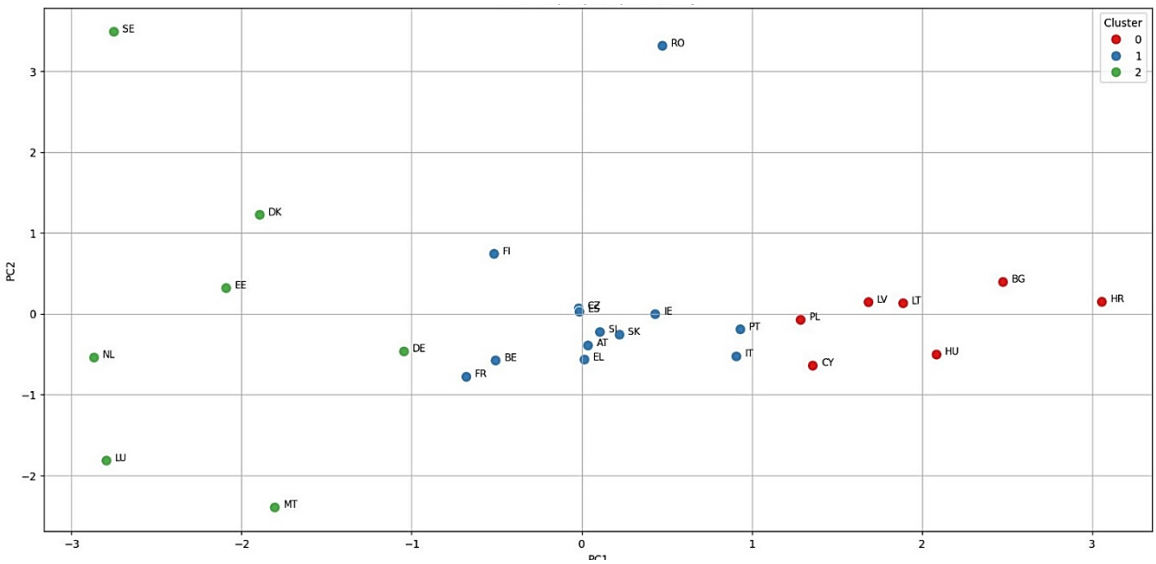


Figure 12. Summary of groups of similar countries in terms of energy transition efficiency.

The first cluster includes countries that stand out for their clear progress in implementing the energy transition process. These countries are characterized by a significant decrease in primary energy consumption per capita and a systematic reduction in the energy intensity of the economy. In addition, there is a marked increase in the share of renewable energy sources in the structure of final energy consumption and a significant reduction in greenhouse gas emissions per capita. This group includes Sweden, Denmark, the Netherlands, Luxembourg, Germany, Estonia, and Malta.

The second cluster includes countries showing gradual, steady progress toward energy transition goals. These countries are experiencing a gradual decline in both energy consumption and greenhouse gas emissions, while increasing the share of renewable energy in the energy mix. However, these changes are less dynamic than in the case of countries in Cluster 1. This group includes France, Finland, Belgium, Austria, Czechia, Portugal, Italy, and Portugal, among other countries.

The third cluster is represented by countries where the energy transition is progressing relatively slowly or regressing (e.g., Croatia). During the period under review, countries in this cluster recorded limited changes in energy efficiency and a slight increase in the share of renewable energy consumption.

In some cases, negative trends were also observed, such as an increase in dependence on energy imports or limited improvement in the situation of households at risk of energy poverty. This group includes Bulgaria, Hungary, Poland, Latvia, Croatia, and Romania, among other countries.

5. Discussion

The energy transition process in European Union countries has a long history. In recent years, however, its dynamics and directions are increasingly determined by the challenges of climate change and the implementation of regulations aimed at mitigating it. Of key importance in this context are the commitments under the European Green Deal [12] and the "Fit for 55" legislative package [16], which aim to achieve EU climate neutrality by 2050.

The energy transition in the EU is mainly aimed at increasing the share of renewable energy sources (RES) in the energy mix and reducing greenhouse gas emissions, as well as improving energy efficiency and reducing energy poverty [32–34,54,60]. Progress toward these goals, however, has been uneven, as member countries differ both in their

baseline levels and in the extent of reforms implemented and the effectiveness of public policies pursued.

To assess the effectiveness of this process, a methodology was developed for its determination based on a set of indicators reflecting key aspects of the process. These include energy security and efficiency, the environmental dimension, primarily related to reducing greenhouse gas emissions and increasing the share of renewable energy sources, and social issues in terms of changes in the level of energy poverty.

The results of the research conducted (Section 4.2) showed that some member states, which in the base year (2013) were at an initial stage of the transformation process, were able to make noticeable and significant progress during the period under review (2013–2023). Examples include Malta (0.77), Luxembourg (0.78), and Cyprus (0.29). However, it is worth noting that the initial situation of these countries "facilitated" them to achieve high indicators in the efficiency of the transformation process. This is due to a lower baseline level of energy intensity or greenhouse gas emissions. Also, the structure of their economies was less energy-intensive than in developed or typically industrial countries. This means that relatively small technological and regulatory changes have led to significant improvements in the values of the indicators studied. In particular, this applies to the use of RES, improvements in energy efficiency, or reductions in greenhouse gas emissions. The performance of these countries is very good, especially when compared with countries such as Sweden (0.23), Finland (0.15), and Denmark (0.21), which (as the results of the [17,21,22] study indicate) were already characterized by a high level of energy transition implementation in 2013. At the time, these countries had well-developed RES systems, low energy intensity of the economy, and relatively low levels of greenhouse gas emissions per capita. This means that their further progress required much more advanced measures, both technological and systemic, as well as greater financial resources and a longer time horizon to achieve more visible changes [45,61]. For this reason, the rate of change in these countries, in percentage terms, is somewhat lower, although their overall level of energy transition sophistication remains the highest in the EU.

A more detailed analysis of the ETEI index values for the surveyed countries indicates significant changes in the trajectory of energy transition efficiency in these advanced economies. Denmark experienced a strong initial transformation impulse (0.10 in the years 2013–2015), with sustained positive, though gradually declining, results and a temporary downturn in 2017–2019 caused by increased dependence on energy imports and rising energy poverty. Similarly, Sweden experienced a short-term negative period of ETEI values (–0.0123 in the years 2015–2017), associated with deteriorating energy efficiency and an increase in energy poverty. However, the country quickly returned to positive values in subsequent years (e.g., 0.1005 in the years 2019–2021). In the long term, these temporary fluctuations did not negatively impact the overall effectiveness of the transformation. As shown in the study referenced in [62], the stability and adaptive capacity of these economies indicate high institutional resilience and the effectiveness of the energy policy pursued, which enables a rapid response to crises and helps maintain a long-term positive direction in the energy transition.

The results of the work also make it possible to identify a group of member states that exhibited lower energy transition efficiency during the period under review. These countries include a significant part of the countries of Central and Eastern Europe, such as Poland (0.11), Bulgaria (0.04), Latvia (0.12), Lithuania (0.12), and Hungary (0.01). This state of affairs is due to the persistently high dependence on fossil fuels, particularly coal, limited access to investment capital, outdated energy infrastructure, and a relatively low level of public awareness of the need to transform the energy system, among other reasons, compared to other EU countries. As Nielsen et al. [63] point out, this is a consequence of

the historical legacy of centrally planned economies and the long-term impact of the former Soviet Union on the region's economic and energy structure. Despite these countries' efforts to decarbonize, their energy policies continue to focus on ad hoc and reactive solutions, resulting in delays in implementing comprehensive and long-term strategies in line with the European Union's climate goals. Undoubtedly, in the case of countries such as Poland and Hungary, the relatively low efficiency of the energy transition process was also influenced by geopolitical and social conditions, which definitely slowed down the energy transition process. This resulted in a limited commitment to EU climate goals, delays in implementing institutional reforms, and a lack of coherent and ambitious decarbonization strategies. This analysis indicates that continuity and long-term planning of public energy and climate policies are necessary to achieve success in the transition process. The goals of the European Green Deal [16] can definitely help in this effort. For it should be remembered that the energy transition is not just a technological issue, but a process with a strong socio-economic dimension, which requires the interaction of many stakeholders and the support of EU and national institutions.

This process, with its high degree of complexity, requires not only technological innovation but also a coherent strategy that integrates social, economic, and environmental goals [32,64,65]. In this context, issues of just transition are becoming increasingly important, which must take into account development differences among member states and provide for support mechanisms dedicated to regions most dependent on traditional energy sectors [66–68]. An example of such measures could be the Just Transition Fund, which, if used appropriately, could help reduce inequalities throughout the transition process.

It seems that further progress in the EU's energy transition process will largely depend on the ability and determination of member states to implement reforms in an integrated manner that takes into account both local circumstances and common European goals.

6. Conclusions and Policy Implications

The topic of energy transition efficiency fits very well with the current state of the global economy. It is important both from the perspective of EU policy and the long-term economic development of member states, in the context of the pursuit of climate neutrality and independence from fossil fuels. Therefore, the paper addresses this extremely important and topical issue, especially in the context of the past and innovative actions that the EU is taking in the field of climate policy. Undoubtedly, it is the region currently leading in the scale and scope of pro-environmental activities.

Based on the developed methodology, a study was carried out with the aim of assessing the effectiveness of the energy transition process in the countries of the European Union for the period 2013–2023. This assessment was carried out on the basis of indices of the dynamics of change in indicators characterizing key aspects of the energy transition. This made it possible to determine the extent to which individual countries effectively pursued energy policy goals aimed at increasing the share of renewable energy sources, improving energy efficiency, reducing greenhouse gas emissions, and increasing energy independence.

The first stage of the research assessed the efficiency of the process, while the second stage analyzed the similarity of the EU-27 countries in terms of the energy transition results achieved.

The research conducted and the results obtained showed the following:

- Luxembourg (0.778), Malta (0.766), and the Netherlands (0.562) have the highest energy transition efficiency index (ETEI) values from 2013 to 2023. The high rating for energy transition efficiency in these countries is the result of dynamic growth in renewable energy consumption, significant improvements in energy efficiency, and a marked decline in per capita greenhouse gas emissions. It should be noted, however,

that such strong dynamics in the change of indicators are due to their low level in the base year, which made the progress over the period of analysis in these countries particularly noticeable.

- Countries with high levels of indicators in the base year (2013), such as Sweden, Denmark, and Finland, did not have as spectacular an effect on transition efficiency as Malta or Luxembourg. This is due to the fact that they were already at an advanced stage of meeting climate and energy targets in the base year. However, compared to the rest of the EU-27, their performance is at a very high level. Despite the smaller scale of indicator increases, these countries have been very successful in building a green economy by increasing the level of energy efficiency, the share of RES, and reducing GHG emissions per capita.
- The only country with a regression in the energy transition process is Croatia. During the period under review, the country failed to increase the share of renewable energy sources in final energy consumption, and additionally increased per capita greenhouse gas emissions and reduced energy efficiency. As a result, Croatia achieved a negative value of the ETEI index, which clearly indicates the deterioration of key parameters of the energy transition and the need to implement decisive corrective measures.

Based on the PCA analysis, three groups of countries (clusters) similar in terms of the efficiency profiles of the energy transition process were identified. The countries in the first cluster, namely, Luxembourg, Malta, the Netherlands, Sweden, and Denmark, made the most progress in this area, significantly increasing the share of RES, reducing per capita GHG emissions, and improving the energy efficiency of their economies. Countries in the second cluster, including Finland, France, and Austria, among others, continued a stable, albeit less intensive, transformation. The third cluster includes countries that are clearly struggling in the transformation process, and their efforts in this area are at an unsatisfactory level.

With regard to the research conducted, the results obtained, and the conclusions made, the following recommendations were developed:

- It is necessary to develop a system for monitoring the effectiveness of the energy transition in EU countries. It should be based on indices of the dynamics of change, allowing for ongoing tracking of progress, identification of problem areas, and effective adjustment of public policies to the pace and direction of change in individual EU countries.
- It makes sense to differentiate energy transition support policies, which should be more flexible and tailored to the specifics of individual member states. In particular, it is advisable to take into account the limited potential of countries with low transition efficiency and provide them with individually tailored support instruments for the sectors and areas showing the greatest delays.

The research conducted and the results obtained confirmed that the efficiency of the energy transition in the EU-27 countries varies strongly and depends on the baseline and a number of internal and external factors. The use of the dynamics index approach and the PCA method made it possible not only to assess the pace of transformation but also to identify groups of countries with similar transformation profiles.

The research conducted also has some limitations, which at the same time may provide directions for future research. First, although the period 2013–2023 covers an important decade of change for EU energy and climate policy, it should be remembered that the energy transition is a long-term process. Therefore, future studies should be expanded to cover more years, in order to capture the effects of the implemented developed strategies and long-term investments. At the same time, it is worth considering extending the period

of analysis to include earlier years as well, such as 2008–2013, to get a more complete picture of the dynamics of change.

Second, it should be borne in mind that the high dynamics of selected indicators in countries starting the transition from a low level may not fully reflect the actual progress of transformation efforts. Therefore, it would be worthwhile for further research to consider an approach that takes into account both the pace of change and the level of progress of the transformation against specific end goals. Future studies should also pay attention to the issue of selecting weights for the indicators used in the analyses. It seems justified to conduct comparative analyses in which the weights are determined using objective (analytical) methods, such as the entropy method or the CRITIC method. Alternatively, applying a hybrid approach that combines both expert assessments and analytical techniques would allow for a more objective evaluation of the impact of the chosen weights on the final research results. Such an approach could contribute to increased transparency and the validity of the assessments of energy transition effectiveness, as well as facilitate the identification of potential discrepancies resulting from the adopted research methodology.

In summary, it can be said that the research conducted allowed a comprehensive assessment of the effectiveness of the energy transition in the EU-27 countries between 2013 and 2023. The methodology used, based on the indices of the dynamics of change and PCA analysis, made it possible to capture the pace and direction of the transition.

It was very important to determine the synthetic energy transition efficiency index (ETEI), which provides a new, non-obvious perspective for analysis. This approach made it possible to compare the effectiveness of each country's actions in terms of its starting point and rate of change.

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