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EVALUATION OF POLAND'S ENERGY TRANSITION PROCESS BETWEEN 2012-2022

Magdalena TUTAK[1*], Jaroslaw BRODNY[2]

[1] Silesian University of Technology; magdalena.tutak@polsl.pl, ORCID: 0000-0003-4781-8697
[2] Silesian University of Technology; jaroslaw.brodny@polsl.pl, ORCID: 0000-0002-6807-4431
* Correspondence author

Purpose: The primary objective of this study is to empirically assess the progress of Poland's energy transition from 2012 to 2022.
Design/methodology/approach: The study employs a multidimensional approach using multi-criteria analytical methods. Specifically, the CRITIC and TOPSIS methods were utilized. The CRITIC method was applied to determine the weights of selected indicators that characterize Poland's energy transition process. These indicators include key parameters such as energy efficiency, the share of renewable energy sources in total production, greenhouse gas emissions, and electricity costs. Subsequently, the TOPSIS method was used to develop an index for assessing Poland's energy transition from 2012 to 2022. This index allows for the evaluation of the changes implemented in each year within the study period.
Findings: The results indicate that Poland has made significant progress in the energy transformation of its economy. The value of the Energy Transformation Assessment Index has markedly increased in 2022 compared to 2012. This improvement reflects the consistent and effective implementation of pro-environmental policies and measures aimed at the sustainable development of both the energy sector and the national economy as a whole.
Practical implications: The developed evaluation methodology offers a universal approach to determining a country's energy efficiency, which can be successfully applied to any country. By utilizing advanced multi-criteria decision analysis methods, this approach considers a broad range of criteria, including energy efficiency, the share of renewable energy sources, greenhouse gas emissions reduction, economic costs, and societal impact. Its versatility allows it to be used for evaluating both individual countries and groups of countries.
Originality/value: This paper introduces a novel approach by using MCDM-type methods to assess the effectiveness of a single country's energy transition process. This comprehensive approach provides a holistic assessment of the energy transition, encompassing dimensions of energy security, economic performance, environmental impact, and social outcomes.
Keywords: energy transition, process efficiency, energy policy, MCDM methods, multi-criteria analysis.
Category of the paper: Research paper.

1. Introduction

Global climate change, including increases in average temperatures, changes in precipitation patterns, and increasingly frequent extreme weather events, has become a serious threat to the entire Earth's ecosystem, including humans (Bolan et al., 2024; Kumar et al., 2021). To mitigate these effects, many countries and regions, including the EU-27, have committed to an energy transition that involves reducing greenhouse gas emissions, increasing the share of (RES) energy sources, and improving energy efficiency.

In recent years, energy transition has emerged as one of the key challenges for many countries, including Poland. This process, which involves transforming energy structures and implementing sustainable development strategies, is a crucial component of global efforts to combat climate change and protect the environment (Mehmood et al., 2024). The energy transition is a complex and multifaceted endeavor aimed at modernizing the energy sector to make it more sustainable, environmentally friendly, and resilient to various fluctuations in the energy market (Miller et al., 2015; Razzaq et al., 2023). This process primarily entails changes in the fuel mix used for energy production and the technologies employed in the power industry. Today, the energy transition encompasses much broader areas and affects all relevant aspects of life. It is generally understood as a shift from an energy system based on conventional sources to one that is based on zero-carbon, primarily RES. Simultaneously, this process is intended to foster economic growth, be environmentally sustainable, and avoid deteriorating the quality of life (Brodny et al., 2024).

The energy transition process thus involves a fundamental transformation in the way energy is produced, distributed, and consumed. Traditionally, many countries have relied on fossil fuels such as coal, oil, and natural gas for their energy systems (Hailes, Vinuales, 2023). While these sources are relatively cheap and accessible, they have serious negative environmental impacts due to the large emissions of carbon dioxide and other harmful substances they produce (Yang et al., 2024). A key objective of the energy transition is therefore to increase the share of renewable energy sources, such as wind, solar, hydroelectric, and biomass, which are less harmful to the environment and help reduce greenhouse gas emissions (Rahman et al., 2022).

In the energy transition process, the European Union is playing a key role in becoming a global leader. The ambitious goals and initiatives it has adopted are designed to reduce the environmental impact of the energy sector without compromising economic development and citizens' quality of life. As part of its energy and climate policy, the EU aims to significantly increase the share of RES in the energy mix and improve energy efficiency. To achieve these goals, it is introducing a range of regulations and strategies to promote investment in green technologies and innovative solutions. This also applies to Poland, an EU member state, which is undergoing an intensive transformation of its energy sector. This transformation is essential to meet the EU's energy and climate policy objectives and to ensure energy security.

Therefore, given the timeliness and complexity of this issue, as well as the long-term nature of the energy transition process, it is crucial to assess the progress made in this area in Poland. This is particularly important since Poland is one of the largest EU countries and falls within the group of developing nations. Evaluating Poland's energy transition process from 2012 to 2022 is a vital step in assessing the effectiveness of the measures implemented during this period and in identifying areas that require further development.

The purpose of the research, the results of which are presented in this paper, was to develop and implement a multidimensional research methodology and conduct an assessment of the progress of Poland's energy transition from 2012 to 2022. The study employed the CRITIC and TOPSIS methods from the MCDM group. The CRITIC method was used to determine the weights of selected indicators characterizing the energy transition process in Poland. These indicators included key parameters such as energy efficiency, the share of RES in total production, greenhouse gas emissions, and electricity costs. Based on the TOPSIS method, an index for assessing Poland's energy transition during the 2012-2022 period was then determined.

2. Materials and methods

The study, which aimed to assess Poland's energy transition process between 2012-2022, was based on a set of 17 key diagnostic variables that characterize the process. The selection of these variables was based on their importance in the context of the energy transition and their ability to reflect the changes taking place in the Polish energy sector. The chosen variables reflect crucial aspects of energy production, consumption, and security, as well as the environmental, economic, and social dimensions of the transition. The selected indicators had to meet the following criteria:

1. **Relevance to the Energy Transition**. The primary criterion for selecting indicators was their direct link to energy transition goals, such as reducing carbon emissions, increasing energy efficiency, and shifting to renewable energy sources. Variables like the share of renewables in the energy mix, energy sufficiency ratio, and Greenhouse Gases (GHG) intensity of energy provide insights into the pace and progress of this transformation.
2. **Comprehensive Coverage of Key Aspects**. To capture a holistic picture of the energy transition, the selected variables span across different domains. This includes economic indicators such as GDP per capita and energy productivity, environmental indicators like GHG emissions and their intensity, and social indicators such as energy poverty (e.g., the population unable to keep homes adequately warm). This broad approach

ensures a balanced assessment of both the achievements and challenges of the energy transition.

3. **Reflecting Key Drivers of Energy Policy**. Several variables, such as energy imports dependency, diversifying the energy mix (HHI), and the energy intensity of production, were included because they are critical to understanding energy security, independence, and the resilience of the energy system. These indicators are essential in evaluating whether Poland is reducing its reliance on external energy sources and promoting a more sustainable, diversified energy mix.
4. **Data Availability and Reliability**. The data for all the selected variables were sourced from the EUROSTAT database, ensuring consistency, reliability, and comparability over the 2012-2022 period. EUROSTAT's comprehensive and standardized datasets allow for a consistent approach in analyzing energy-related trends across the years, enabling a robust and objective evaluation.
5. **Ability to Reflect Change**. Each selected indicator was chosen based on its capacity to reflect measurable changes in the energy sector. For example, energy productivity (measured in euros per kilogram of oil equivalent) offers an insight into how efficiently energy is being utilized in relation to economic output, while energy intensity and GHG) intensity show the effectiveness of energy policies in reducing carbon emissions relative to energy consumption or Gross Domestic Product (GDP).

These variables included:

- total primary energy supply per capita, tons of oil equivalent (TOE);
- primary energy consumption per capita, tons of oil equivalent (TOE);
- energy imports dependency, %;
- diversifying the energy mix - the Herfindahl-Hirschman Index (HHI);
- energy sufficiency ratio;
- share of non-renewables in energy mix, %;
- share of renewables energy mix, %;
- GDP per capita, Euro;
- energy productivity, euros per kilogram of oil equivalent (KGOE);
- energy intensity, kilograms of oil equivalent (KGOE) per thousand euros;
- electricity prices for non-household consumers (consumption from 500 MWh to 1,999 MWh, all taxes and levies included), euros/kilowatt;
- electricity prices for household consumers (consumption from 2,500 kWh to 4,999 kWh, all taxes and levies included), euro/kilowatt;
- total GHG per capita, (tons CO_2 eq.);
- GHG Intensity of Energy, (kg CO_2 eq./toe);
- total GHG - GDP Intensity (tons CO_2 eq./M€);
- RES share in gross final energy consumption, %;
- population unable to keep home adequately warm by poverty status, %.

All data used in the study came from the EUROSTAT database and covered the years 2012-2022.

The essential calculations required to determine the value of the Index of Assessment of the Energy Transformation Process (IAETP) for Poland were conducted using multi-criteria analysis methods. This advanced technique considers multiple dimensions, or diagnostic variables, simultaneously, which is crucial for evaluating complex processes like energy transformation. To determine the weights of the indicators, the CRITIC method (Criteria Importance Through Intercriteria Correlation) was employed. These calculated weights were subsequently integrated into the core assessment using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method.

The CRITIC method is a well-regarded approach in multi-criteria decision analysis, utilized for determining the relative importance of criteria in evaluation and decision-making processes. This method bases its calculations on an analysis of the correlation between criteria and the standard deviation of each criterion's values. Consequently, the CRITIC method considers both the data dispersion (standard deviation) for each criterion and the strength of interdependencies (correlations) between criteria (Diakoulaki et al., 1995). The calculation steps involved in this method are as follows:

- To construct a decision matrix:

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

- To normalize a decision matrix:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; for\ benefit\ criterion \tag{2}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}};\ for\ cost\ criterion \tag{3}$$

- To determine the standard deviation (SD) values for the criteria (diagnostic variables) included in the assessment:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(r_{ij} - \overline{r_{ij}}\right)}{n-1}} \tag{4}$$

- To determine the values of correlation coefficients between the criteria (diagnostic variables) included in the assessment:

$$r_{jk} = \frac{\sum_{i=1}^{n}\left(r_{ij} - \overline{r_{ij}}\right)\left(r_{ij} - \overline{r_{ij}}\right)}{\sqrt{\sum_{i=1}^{n}\left(r_{ij} - \overline{r_{ij}}\right)^2 \sum_{i=1}^{n}\left(r_{ik} - \overline{r_{ik}}\right)^2}} \tag{5}$$

- To determine the value of the Information Capacity measure (C_j):

$$C_j = SD\sum_{i=1}^{n}\left(1 - r_{jk}\right) \tag{6}$$

- To determine the weights of the evaluation criteria:

$$w_{ij} = \frac{C_j}{\sum_{i=1}^{n} C_j} \tag{7}$$

The TOPSIS method is a popular technique for multi-criteria decision analysis. It involves evaluating and comparing different alternatives (in the paper, the alternatives are the years under study) based on the distance from the ideal solution (the best possible solution) and from the anti-ideal solution (the worst possible solution) (Brodny, Tutak, 2023; Hwang et al., 1993). The process of determining the evaluation index involves the following steps:

- To construct a decision matrix (equation 1);
- To normalize data:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x^2{}_{ij}}} \tag{8}$$

- To construct a normalized weighted matrix:

$$v_{ij} = r_{ij} \cdot w_j \tag{9}$$

- To identify the ideal (A^{+}) and anti-ideal (A^{-}) solution:

$$A^{+} = \{v_1^{+}, v_2^{+}, \dots, v_m^{+}\};$$
$$v_j^{+} = \left\{\left(\max_i v_{ij} | j \in S\right), \left(\min_i v_{ij} \; | j \in D\right) | i = 1, 2, \dots, n\right\} \tag{10}$$

$$A^{-} = \{v_1^{-}, v_2^{-}, \dots, v_m^{-}\};\ v_j^{-} = \left\{\left(\min_i v_{ij} | j \in S\right), \left(\max_i v_{ij} \; | j \in D\right) | i = 1, 2, \dots, n\right\} \tag{11}$$

- To calculate the distance from the ideal (D_i^{+}) and anti-ideal (D_i^{-}) solution:

$$D_i^{+} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^{+}\right)^2} \tag{12}$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^{-}\right)^2} \tag{13}$$

- To calculate the measure of proximity to the ideal solution:

$$P_i = \frac{D_i^{-}}{D_i^{-} + D_i^{+}} \tag{14}$$

- To make a ranking of alternatives based on the evaluation index (a measure of closeness to the ideal solution). The alternative with the highest value is the best alternative.

The methodology developed in this way was used to assess changes in Poland's energy transition process from 2012 to 2022.

3. Results and discussion

Based on the methodology developed and described (in Section 2), a study was conducted, the results of which are presented and discussed in this section.

3.1. Preliminary statistical analysis of the diagnostic variables adopted for the study

Table 1 shows the basic statistical parameters of the indicators (diagnostic variables) adopted for the study.

Table 1.
Basic descriptive statistics of the adopted indicators (diagnostic variables)

Indicators	Mean	Min	Max	Standard deviation	Coefficient of variation	Skewness	Kurtosis	Index of rate of change, %
X1	2.69	2.48	2.94	0.15	5.67	0.16	-1.13	110.00
X2	2.56	2.35	2.80	0.15	5.83	0.20	-1.07	109.63
X3	36.81	26.29	46.00	7.29	19.81	-0.08	-1.86	145.23
X4	0.33	0.28	0.37	0.03	9.15	-0.00	-1.57	83.76
X5	0.67	0.58	0.77	0.07	10.99	0.17	-1.98	78.57
X6	0.90	0.87	0.91	0.02	1.93	-0.37	-1.87	95.47
X7	0.10	0.09	0.13	0.02	16.58	0.37	-1.87	146.50
X8	12375.18	10000.00	15447.00	1966.97	15.89	0.32	-1.38	154.47
X9	4.44	3.91	5.29	0.41	9.22	0.67	0.41	135.26
X10	226.72	189.04	255.71	20.19	8.91	-0.25	-0.17	73.93
X11	0.12	0.10	0.15	0.02	14.26	1.30	0.97	133.22
X12	0.15	0.14	0.18	0.01	7.10	2.04	5.07	119.00
X13	10.40	9.83	10.86	0.31	3.02	-0.15	-0.25	98.92
X14	3857.02	3624.80	4089.96	179.78	4.66	-0.09	-2.01	89.58
X15	852.70	672.85	1017.21	111.86	13.12	-0.10	-1.07	66.15
X16	0.13	0.11	0.17	0.02	17.58	0.32	-2.03	154.07
X17	6.80	3.20	13.20	3.28	48.19	0.86	-0.11	37.12

Source: Own elaboration.

When analyzing the results, it can be concluded that the average primary energy consumption per capita in Poland during the analyzed period was 2.56 TOE, while the availability per capita was 2.89 TOE. The lowest primary energy consumption per capita occurred in 2013, at 2.35 TOE, while the highest was in 2022, at 2.80 TOE. On average, Poland imported about 37% of its energy between 2012 and 2022. The energy mix averaged 90% non-renewable sources and 10% renewable sources. The highest share of renewable sources in the energy mix was 13% in 2022, while the lowest share was 8.8% in 2013. The average share of renewable energy sources in final energy consumption was 13%.

During the review period, the average value of energy productivity was 4.44 euros per KGOE, and energy intensity was 226.72 KGOE per 1000 euros. From 2012 to 2022, average per capita greenhouse gas emissions were 10.40 tons of CO_2 equivalent, with the highest emissions recorded in 2018 at 10.86 tons of CO_2 equivalent and the lowest in 2020, during the SARS-CoV-2 pandemic, at just under 9.9 tons of CO_2 equivalent.

3.2. Weight values of the indicators included in the study

In the next stage of the research, calculations were conducted to determine the values of the weights assigned to the indicators used in the empirical evaluation of Poland's energy transition process from 2012 to 2022. The analytical objective method, specifically the CRITIC method, was employed for these calculations. By determining these weights, the impact of individual indicators on Poland's energy transition process during the study period was accurately assessed. The results of these calculations are presented in Figure 1.

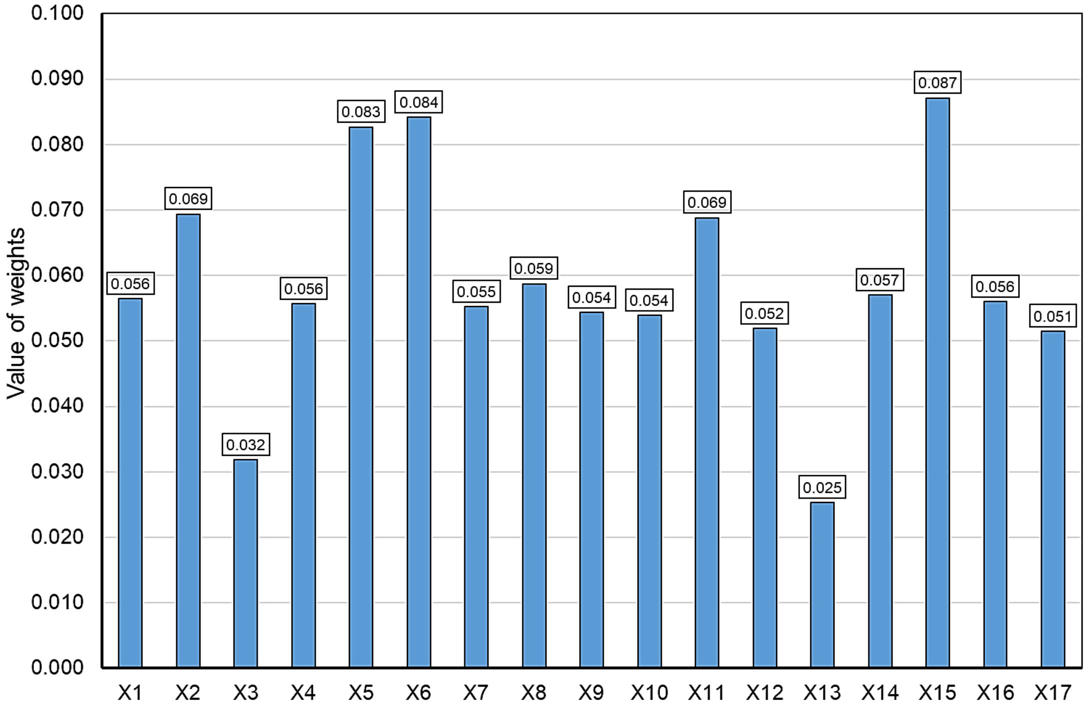

Figure 1. The values of the weights of indicators characterizing the energy transition in Poland determined by the CRITIC method.

Source: Own elaboration.

The analyzed indicators have varying weights, reflecting their relative importance in evaluating the energy transition process. Indicators such as GHG intensity to GDP (X15), share of non-renewable sources in the energy mix (X6), and energy self-sufficiency (X5) carry the highest weights, underscoring their significance to the research. Conversely, indicators like dependence on energy imports (X3) and total GHG per capita (X13) have the lowest weights among all indicators, though they remain important for assessing the process.

3.3. Assessment of Poland's energy transition process in 2012-2022

Using the determined weights for the indicators and applying the TOPSIS method, an index for assessing Poland's energy transition process (IAETP) from 2012 to 2022 was calculated. This period was chosen for analysis because it encompasses the most significant transformations in the energy sector. Between 2012 and 2022, Poland experienced substantial changes in energy policy, including increased use of renewables, alterations in the energy mix, and the implementation of new regulations aimed at improving energy efficiency and reducing greenhouse gas emissions. These factors contribute to the complexity of the energy transition process.

From 2012 to 2022, Poland's total primary energy supply per capita (Fig. 2) exhibited a generally rising trend, starting at 2.56 tons of oil equivalent in 2012, peaking at 2.94 tons in 2021, and then falling to 2.81 tons in 2022. This increase suggests a growing energy demand driven by economic development and increased industrial activity. Similarly, primary energy consumption per capita (Fig. 2) rose from 2.44 tons in 2012 to 2.80 tons in 2021, before decreasing to 2.67 tons in 2022. The rise in primary energy consumption reflects increased energy needs due to economic growth, higher productivity, and improved living standards. The noticeable rise in energy consumption up to 2021, followed by a decline in 2022, may indicate influences such as fluctuating energy prices, changes in economic structure, or the effects of policies aimed at improving energy efficiency.

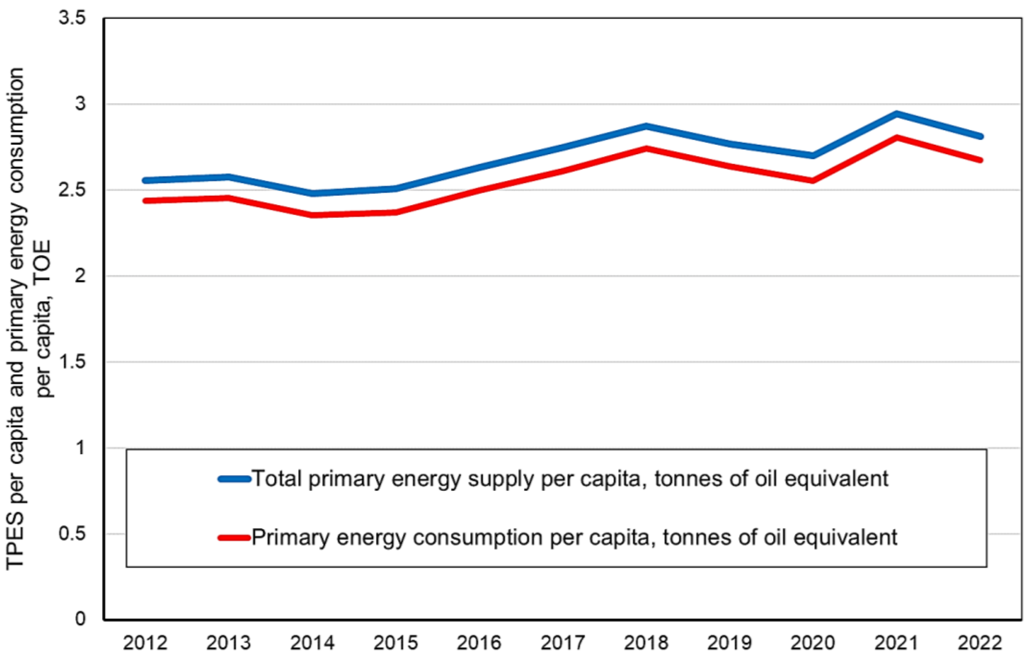

Figure 2. Changes in primary energy supply per capita and primary energy consumption per capita from 2012 to 2022.

Source: Own elaboration.

The decrease in both total primary energy supply per capita and primary energy consumption per capita in 2020 compared to 2019 can be attributed to the COVID-19 pandemic. In 2020, many economic sectors, including industry, transportation, and services, experienced significant reductions in activity due to the pandemic. Restrictions such as factory closures, travel limitations, and decreased industrial activity led to a drop in overall energy consumption. In 2021, with the easing of pandemic restrictions and a gradual recovery in economic activity, both indicators rose, reflecting an increase in energy demand and economic recovery. The decline in 2020 underscores the pandemic's impact on the energy sector and highlights the vulnerability of energy consumption to global crises and changing economic conditions.

The energy import dependency ratio (Fig. 3) increased from 31.67% in 2012 to 46.00% in 2022. This rise signifies a greater reliance on energy imports due to increased demand and a decline in domestic energy production from local resources. It also reflects the growing importance of foreign energy sources in Poland's energy balance. The share of non-renewable sources in the energy mix (Fig. 3) decreased slightly from 91.13% in 2012 to 87.00% in 2022. Despite this reduction, non-renewable sources continue to dominate Poland's energy mix, indicating the challenges of a rapid transition to a more sustainable energy system. Conversely, the share of renewable sources increased from 8.87% in 2012 to 13.00% in 2022, demonstrating Poland's progress toward energy transition. Notably, between 2018 and 2020, the share of renewable sources exceeded 11%, reflecting growing efforts to develop renewable energy.

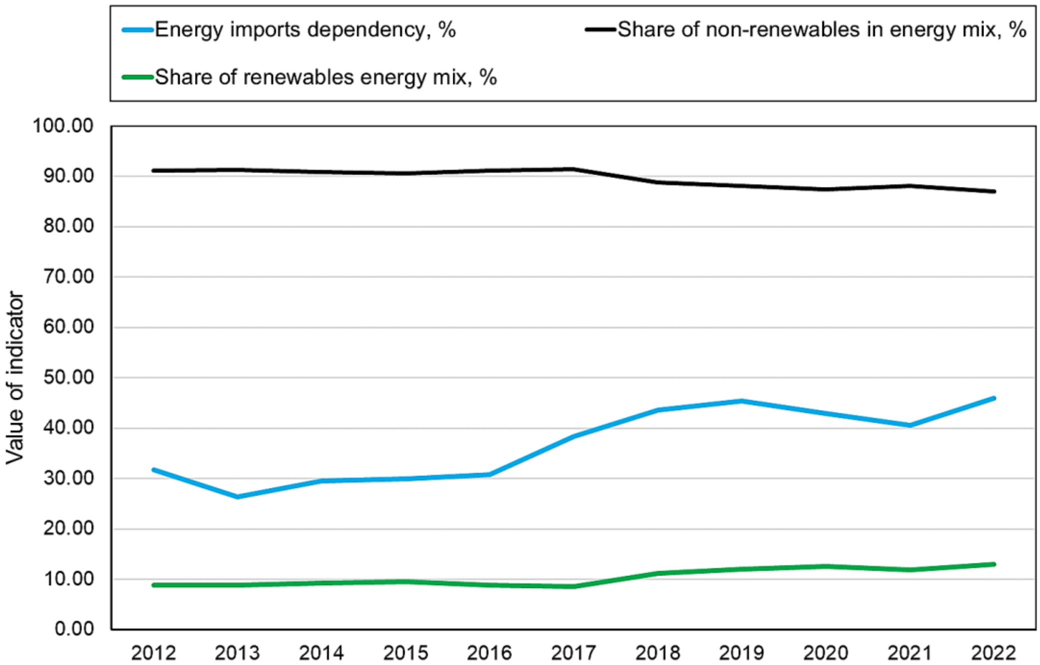

Figure 3. Changes in dependence on energy imports and the share of non-renewable and renewable sources in Poland's energy mix from 2012 to 2022**.**

Source: Own elaboration.

Analysis of data on the diversification of the energy mix, as measured by the Herfindahl-Hirschman Index (HHI) from 2012 to 2022 (Fig. 4), reveals changes in Poland's energy structure. The HHI, which reflects the concentration of energy sources in the energy mix, indicates the degree of diversification. Over the analyzed period, the HHI value decreased gradually from 0.36 in 2012 to 0.30 in 2019, remaining at 0.30 until 2022. This decline suggests that Poland's energy mix has become more diversified, reflecting an increased use of different energy sources.

Concurrently, the energy self-sufficiency index (Fig. 4), which is the ratio of energy production to consumption, demonstrated a declining trend throughout the period. Its value decreased from 0.766 in 2012 to 0.578 in 2021, before rising to 0.602 in 2022. The decline in the energy self-sufficiency index indicates a reduction in Poland's energy production capacity relative to its consumption.

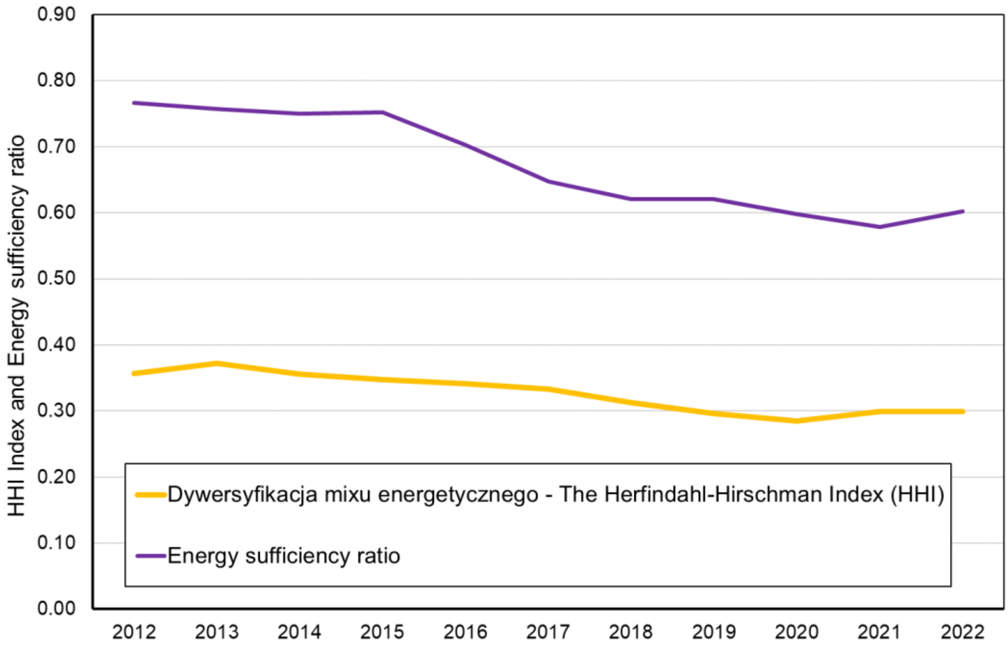

Figure 4. Changes in the diversification of Poland's energy mix and its energy self-sufficiency in 2012-2022**.**

Source: Own elaboration.

During the period under review (2012-2022), GDP per capita increased from €10,000 in 2012 to €15,447 in 2022 (Fig. 5). This over 50% increase reflects the country's overall economic development, improved living standards, and higher per capita income. This growth suggests that the energy transition has not disrupted the country's economic progress.

At the same time, energy intensity (Fig. 5), measured as kilograms of oil equivalent per thousand euros of GDP, exhibited a downward trend. In 2012, it was 255.71 kg/k€, and by 2022, it had decreased to 189.04 kg/k€. This decline indicates improved energy efficiency, with less energy consumption required per unit of economic output. This positive trend may result from the implementation of more efficient technologies, a shift to less energy-intensive production processes, or an increase in the share of more efficient energy sources.

It is notable that the decline in energy intensity was not uniform throughout the period. Between 2014 and 2019, energy intensity decreased gradually, reflecting ongoing efforts to enhance efficiency. However, in 2020, despite a decline in GDP due to the COVID-19 pandemic, energy intensity remained low. This suggests that the reduced energy demand was related to the economic context of the pandemic rather than a reduction in energy efficiency.

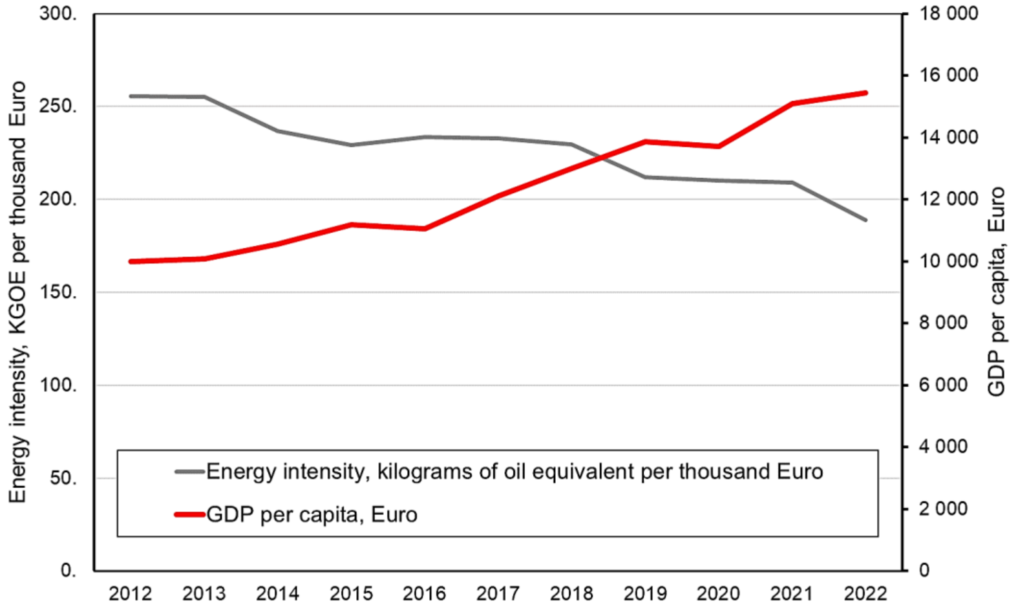

Figure 5. Changes in the value of GDP per capita and energy intensity from 2012 to 2022.
Source: Own elaboration.

The next indicators that were included in the energy transition assessment were energy prices for domestic users and industrial consumers (Fig. 6).

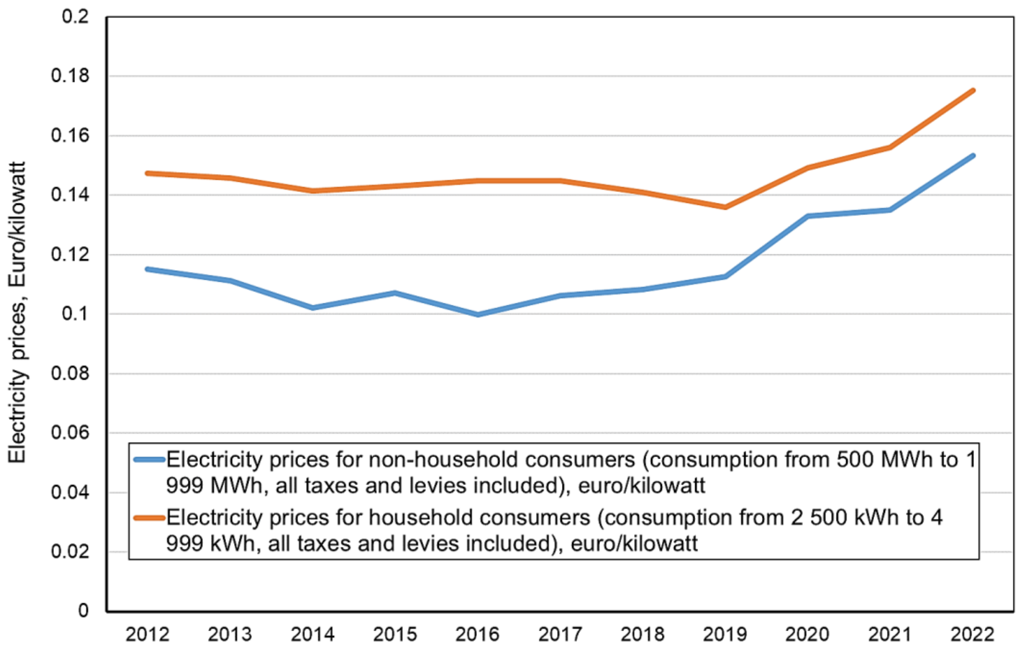

Figure 6. Formation of average electricity prices for residential and industrial consumers in 2012-2022.
Source: Own elaboration.

In the case of electricity prices for industrial consumers (those consuming between 500 MWh and 1,999 MWh per year), prices were relatively stable in the early years of the period under review. In 2012, the average price was €0.12 per kilowatt-hour. This price fluctuated in the following years, with a downward trend in the first part of the period, reaching a low of €0.10 in 2016. Prices then began to rise, reaching €0.13 in 2020, €0.14 in 2021, and €0.15 in 2022. For household electricity prices (consuming between 2,500 kWh and 4,999 kWh per year), prices were initially higher and more volatile. In 2012, the price was €0.15 per kilowatt-hour, which decreased to €0.10 in 2014. Prices then rose to €0.145 in 2016 and remained at that level until 2018, when they fell to €0.14. Starting in 2019, prices began to increase again, reaching €0.14. From 2020, the rise became more pronounced, with prices reaching €0.15 in 2020, €0.16 in 2021, and €0.18 in 2022. The increase in electricity prices in recent years is attributed to rising raw material costs, regulatory issues related to CO_2 emissions, the European Union's climate policy (including the Emissions Trading Scheme), and the geopolitical situation.

Analysis of data on greenhouse gas emissions per capita, GHG emissions intensity per unit of energy, and GHG emissions relative to GDP in Poland from 2012 to 2022 (Fig. 7) reveals varied trends and developments within the context of the country’s energy transition.

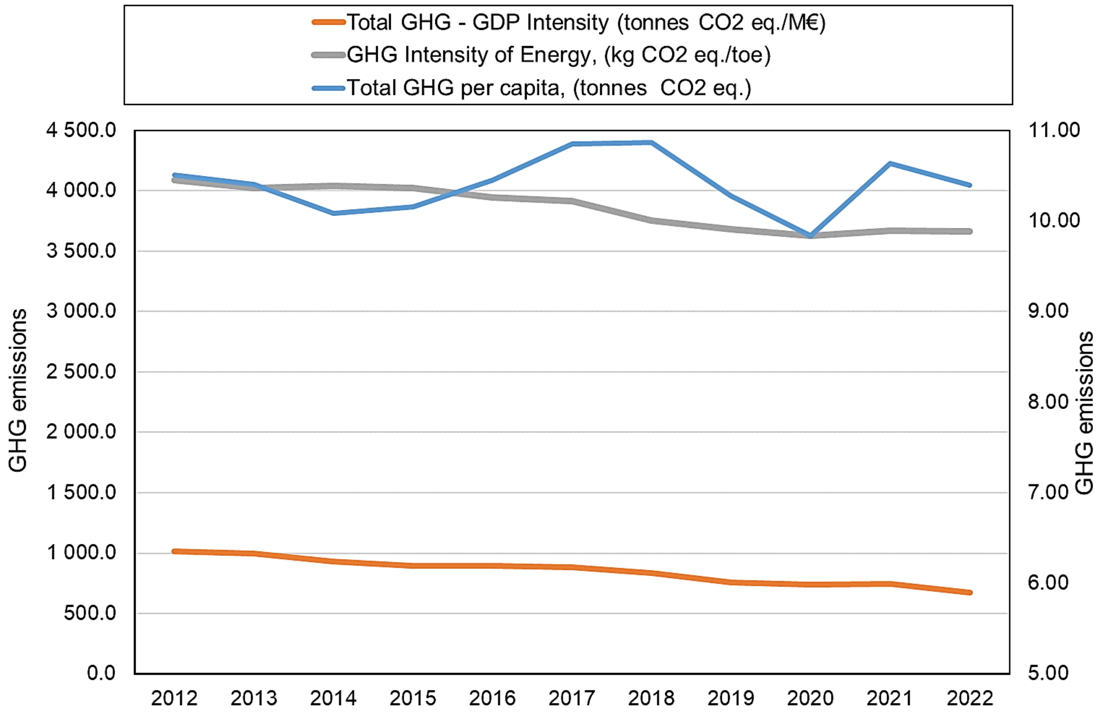

Figure 6. Shape of greenhouse gas emissions in Poland in 2012-2022.

Source: Own elaboration.

From 2012 to 2022, per capita greenhouse gas emissions showed a downward trend. Emissions decreased from 10.51 tons of CO_2 equivalent per capita in 2012 to 10.39 tons in 2022. The lowest per capita emissions were recorded in 2020 at 9.83 tons, a reduction attributed to lower energy consumption during the COVID-19 pandemic and its associated economic constraints.

The intensity of GHG emissions per unit of energy, expressed in kilograms of CO_2 equivalent per ton of oil equivalent (kg CO_2 eq./toe), also exhibited a downward trend. This intensity decreased from 4,089.96 kg CO_2 eq./toe in 2012 to 3,663.69 kg CO_2 eq./toe in 2022. This decline indicates progress in improving energy efficiency and reducing emissions within the energy sector. The most significant reduction in GHG emission intensity occurred between 2018 and 2019, likely due to the adoption of more advanced technologies and an increase in the share of renewable energy sources in the energy mix.

The intensity of GHG emissions relative to GDP, measured in tons of CO_2 equivalent per million euros of GDP, fell from 1,017.2 tons in 2012 to 672.85 tons in 2022. This substantial improvement reflects significant progress in the decarbonization of Poland's economy, attributable to both increased energy efficiency and structural changes within the economy. The most notable decrease in emissions intensity relative to GDP was observed between 2018 and 2020, suggesting improvements in overall efficiency and shifts in the industrial and service sectors.

From 2012 to 2022, the share of renewable energy sources in gross final energy consumption exhibited an overall upward trend (Fig. 7). In 2012, this share was 10.955%, and it increased to 16.879% by 2022. The most significant rise occurred between 2017 and 2018, when the share jumped from 11.059% to 14.936%.

Additionally, the percentage of the population unable to maintain adequate heat at home due to poverty decreased markedly during the review period, reflecting improved living conditions. In 2012, 13.2% of the population faced this issue, but by 2022, this percentage had dropped to 5% (Fig. 7). The most substantial decrease in this percentage was observed between 2013 and 2015, falling from 11.4% to 7.5%. This reduction was likely due to improved economic conditions during this time.

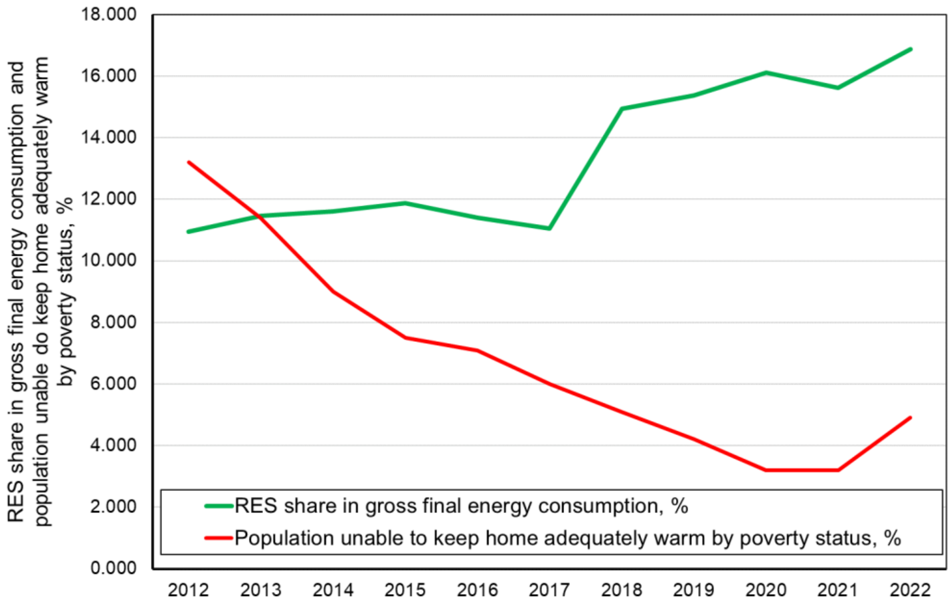

Figure 7. Changes in renewable energy in gross final energy consumption and the development of the energy poverty index in Poland from 2012 to 2022.

Source: Own elaboration.

The values of the indicators and the values of their weights, presented in Figures 2-7 (Figure 1), had a direct impact on the values of the index for assessing Poland's energy transition process (IAETP), in 2012-2022. The values of this index for this period are summarized in Figure 8.

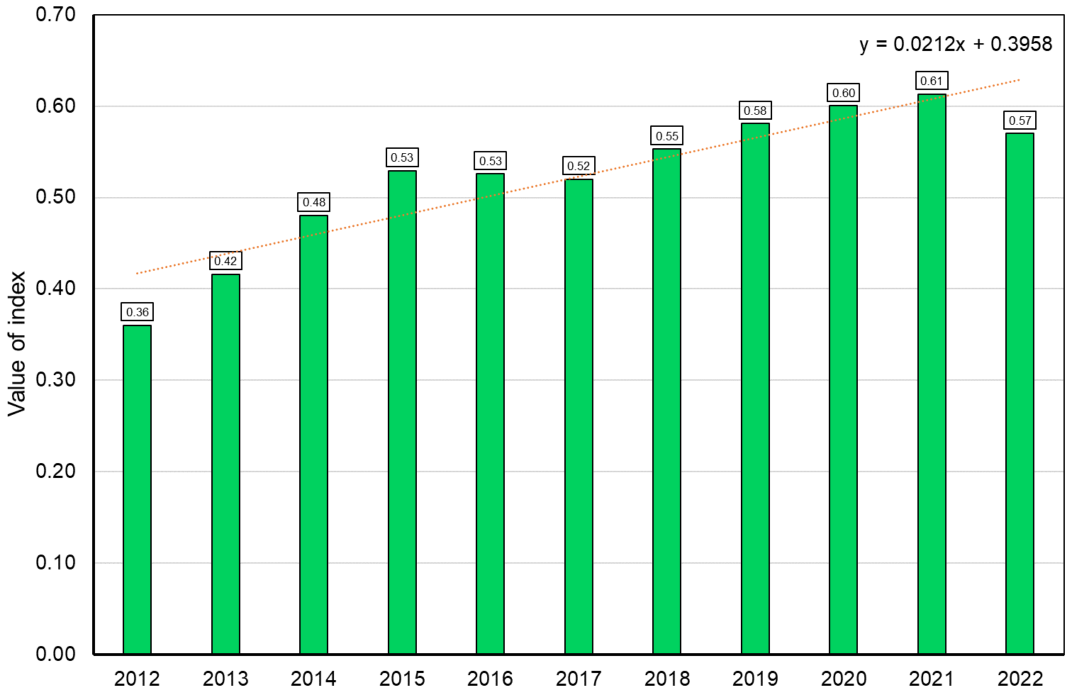

Figure 8. Values of the index for assessing Poland's energy transition process (IAETP) in 2012-2022**.**
Source: Own elaboration.

Analyzing changes in the index for assessing Poland's energy transition process from 2012 to 2022 reveals significant developments in the country's progress. In 2012, the index stood at 0.36, indicating that Poland was at the initial stage of implementing its energy transition policy. The index increased to 0.42 in 2013 and 0.48 in 2014, reflecting a growing commitment to improving energy efficiency and expanding renewable energy sources (RES).

By 2015 and 2016, the index value rose to 0.53, suggesting some stabilization and consolidation of the achievements in the energy transition. From 2017 onward, the index continued to grow, reaching 0.55 in 2018 and 0.58 in 2019, indicating an accelerated pace in the energy transition, driven by a higher share of RES in the energy mix and overall energy use. The highest index value was achieved in 2021 at 0.61. However, in 2022, the index value dropped to 0.57, signaling new challenges in the implementation of transformation policies. This decline can be attributed to factors such as increased GHG emissions in 2021, rising energy poverty, and higher electricity prices.

Despite this decline, the overall upward trend observed in previous years highlights positive progress in the energy transition process. Between 2012 and 2022, Poland achieved substantial advancements in its energy sector, contributing to noticeable progress in decarbonizing the national economy. However, the progress could have been more pronounced if not for Poland's heavy reliance on conventional energy resources. The availability and low costs of fossil fuels have historically dampened public and political enthusiasm for transitioning away from them.

Although Poland continues to face challenges related to its reliance on coal and other fossil fuels, it is making steady progress toward diversifying its energy mix. The development of RES, such as wind and photovoltaic power, along with numerous initiatives to improve energy efficiency in industrial, transportation, and residential sectors, demonstrates ongoing efforts toward a more sustainable energy system (Kochanek, 2022; Rabbi et al., 2022). Importantly, these transformations have not negatively impacted the country's economic development or energy security.

Nevertheless, some studies suggest that energy transitions can temporarily affect energy security and economic growth rates (Li, Jang, 2019). Rapid shifts to renewable energy sources often involve high investment costs and technical challenges, potentially leading to temporary energy supply issues and higher energy costs (Hassan et al., 2024). This has been evident in Poland since 2019, with rising costs in energy production from traditional sources, increased energy commodity prices on international markets, and geopolitical factors contributing to higher energy costs.

4. Conclusions

Based on the developed methodology, a study was conducted to assess the effectiveness of the energy transition process in Poland from 2012 to 2022. The assessment considered key aspects of the process, including energy security, economic issues, climate impact, and social aspects.

The research revealed the following findings:

- The energy transition process in Poland is relatively slow. Despite positive effects, changes have been gradual compared to global standards, national needs, and EU-27 requirements.
- There has been a noticeable increase in the share of renewable energy sources, but it remains insufficient to fully address the country's growing energy needs and meet greenhouse gas emission reduction targets.
- Energy security issues, while relatively stable, require further action to ensure long-term energy independence.
- The energy transition process has not negatively impacted economic development. The value of GDP per capita increased by nearly 50% compared to the base year.
- There have been no significant social costs associated with the energy transition, as indicated by the Energy Transition Social Index, which shows no increase in the problem of energy poverty.

In light of these results, it is necessary to accelerate Poland's energy transition and invest further in environmentally friendly technologies. This approach will better address the challenges related to energy security, climate change, and social needs. Utilizing the results to manage transformation processes more effectively should lead to improved outcomes, both in terms of the overall IAETP index and the individual sub-indices.

5. Research limitations and directions for future research

The conducted research provided significant insights into the energy transition process in Poland; however, it is associated with certain limitations that must be considered when interpreting the results.

Firstly, the analysis was conducted exclusively for Poland, limiting the ability to compare the results with the situation in other countries. Energy transition is a global process, and the economic, social, and political diversity of individual nations can significantly influence the pace and effectiveness of this process. In light of the identified limitations, future research could be expanded and complemented by new approaches that enable a more comprehensive assessment of the energy transition process.

Expanding the research to include other countries, particularly those with similar levels of development and energy challenges, would allow for a comparative analysis of Poland's results with other regions. Such a comparative study would enable the identification of best practices and more effective transition strategies.

Another limitation is the relatively short time frame of the research, covering the years 2012–2022. While this ten-year period is sufficient to analyze the initial effects of the transition, it may be inadequate for capturing long-term trends and assessing the full impact of the transition on the economy, society, and environment.

An essential direction for future research is extending the time frame to capture long-term trends and evaluate the impacts of the transition in the context of changing economic and technological conditions.

The results obtained from this study can guide policymakers and industry stakeholders in shaping future energy strategies. The methodology proposed in this study offers a flexible framework that can be adapted to various national contexts and used to evaluate the progress of energy transition processes.

List of abbreviations

C_i	–	Information Capacity
CO_2	–	Carbon Dioxide
CRITIC	–	Criteria Importance Through Intercriteria Correlation
€	–	Euro
GDP	–	Gross Domestic Product
GHG	–	Greenhouse Gases
HHI	–	the Herfindahl-Hirschman Index
IAETP	–	Index of Assessment of the Energy Transformation Process
kg	–	kilogram
KGOE	–	kilogram of oil equivalent
MWh	–	Megawatt-hour
RES	–	Renewable Energy Sources
SD	–	standard deviation
TOE	–	tons of oil equivalent
TOPSIS	–	Technique for Order Preference by Similarity to Ideal Solution
w_{ij}	–	the weights of the evaluation criteria

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