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Sustainability Development: Assessment of Selected Indicators of Sustainable Energy Development in Poland and in Selected EU Member States Prior to COVID-19 and Following the Third Wave of COVID-19

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Abstract: An important question in the literature on climate change and sustainable development is the relationship between countries' economic growth, household electricity consumption and greenhouse gas emissions. Despite the ongoing COVID-19 pandemic and related economic restrictions, sustainable economic growth remains at the forefront of the global development agenda. However, given the strong relationship between the ever increasing electricity consumption and greenhouse gas CO_2 emissions, an increasing number of scientists have been questioning the feasibility of the planned emission reduction. In my research, I strove to determine whether there exists a relationship between the change in the structure of electricity consumption of households in selected EU Member States (15 countries), the impact of innovation, changes in electricity prices and economic growth, and CO_2 emissions in 2007–2019, prior to the outbreak of the COVID-19 pandemic, and following its third wave (2021). The aim of the article is to propose a synthetic index to assess the degree of sustainable energy development (SISED) in selected EU countries. Multiobjective decision analysis (MODA) was applied in order to assess the sustainable energy development of the selected European countries. Research findings may contribute to both literature and practice if they are applied by individual EU countries in the process of formulating directions aimed at achieving sustainable energy development.

Keywords: COVID-19; sustainable energy development; households

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1. Introduction

All human activity, including economic activity, ought to avoid irreversible damage to the environment and nature through using renewable natural resources in a sustainable manner. However, achieving this goal requires far-reaching, structural changes in the way our cities and entire economies function [1].

The twenty-first century is, undoubtedly, the century of urban spaces. There has been a rapid development of cities, which for an increasing number of people perform vital functions and become centers of numerous economic activities.The United Nations Department of Economic and Social Affairs predicts that the world population will reach 9.7 billion by 2050, 2 billion more than today. By 2050, approx. 70% of the world's population will live in cities, compared to 50% today [2]. Europe is one of the most urbanized continents, with more than 2/3 of the population living in cities [2]. According to the IESE Cities in Motion Index 2020, the world's smartest cities are London, New York and Paris. However, smart does not mean sustainable. The example of Paris, in particular, shows the scale of efforts that city authorities will need to undertake in terms of ecological action, including climate change. For example, in the center of Paris, congested by car transport, CO_2 levels during the rush hour exceed twofold the limit set by the WHO [3].

Countries and cities, therefore, play a vital role in attaining the sustainability objective and in preventing a climate catastrophe: they are the source of problems but, owing to their culture of innovation, also of solutions. The EU is also motivated by the idea of the European Green Deal, which sets the ambitious goal of turning Europe into a climate-neutral continent by 2050.

This is why almost all EU funds, including the Reconstruction Fund (which is to counteract the effects of the pandemic) are attributed to projects which guarantee that over 30 percent of funding will be spent on projects aimed at achieving climate neutrality. The scale and complexity of challenges faced by countries (as socio-economic organisms) and city authorities mean that no single concept recognized in the literature and practice of management for assessing sustainable energy development is sufficient.

Our use of energy is the very basis of the functioning of economies. The development of humanity and the economic world has always been related to the use of energy. This is why energy is one of the factors of sustainable development. The relationship between energy and sustainability can be both positive as well as negative. On the one hand, it enables technological development, which contributes to the improvement of living conditions [4–7]. On the other hand, the use of energy, e.g., for the production of goods, may cause environmental pollution [8–10].

Currently, energy is generated mainly from fossil fuels. However, this method of production is harmful to the environment and causes the emission of harmful substances to the atmosphere (greenhouse gases). According to the World Economic Forum, the current changes in the energy sector are related, inter alia, to the emergence of new technologies, to climate change, and dwindling natural resources [11].

Given the ongoing climate changes, it necessary to move towards economies that are as climate neutral as possible. One of the pillars of such transformation is the improved energy efficiency of the processes of production, transmission and use of energy; they all form part of a sustainable energy policy. An important question in the literature on climate change and sustainable development is, therefore, the relationship between countries' economic growth, household electricity consumption and CO_2. Despite the ongoing COVID-19 pandemic and all related economic restrictions, sustainable economic growth remains a major global concern, as the current global amount of CO_2 emissions is causing an increasing number of scientists to question the feasibility of the planned emission reduction.

Research on sustainable energy development and its level has been conducted for many years. However, no studies exist that would assess the level of sustainable energy development in the European Union Member States over the period of 2007–2021, with an examination of these relationships in the period following the third wave of the pandemic, using simplified indicators. This research gap is filled by the presented study.

The aim of the article is to propose a synthetic index to assess the degree of sustainable energy development (SISED) in selected EU countries. Two main dimensions have been selected for this purpose: (1) Economic Indices and (2) Energy and Climate. Data from 15 countries, i.e., Austria, Denmark, Finland, France, Greece, Spain, the Netherlands, Ireland, Germany, Norway, Poland, Portugal, Sweden, Great Britain and Italy has been analyzed.

My research was to allow us to determine the existence of a relationship between the change in the structure of electricity consumption in EU households, the impact of innovation, changes in electricity prices and economic growth, and CO_2 emissions in 2007–2019, i.e., before the outbreak of the COVID-19 pandemic, and following its third wave (January 2020–September 2021). In order to assess the energy sustainability of the chosen European countries, the multiobjective decision analysis (MODA) was applied. Detailed information is presented in Section 3. Materials and Methods.

2. Literature Review

2.1. Sustainable Energy in EU

With the deteriorating environment and dwindling natural resources, the European Union has begun to take action to transform economies and counteract climate change.

At the same time, Europe's overarching goal is sustainable development, as indicated in Article 2 of the Lisbon Treaty [12]. According to this concept, one of the most important goals is [13–19]: (1) creating a stable environment, (2) achieving sustainable consumption and production (3) minimizing poverty.

The European Union is a key actor in the global climate policy and is the creator of comprehensive regulatory standards in the area of climate protection and the reduction of CO_2 emissions. The EU Emissions Trading Scheme (EU ETS), created in 2005, is the world's largest international trading system for CO_2 emissions. The system is a key element of the European Union's climate policy and an essential tool for reducing greenhouse gas emissions.

In 2008, the European Parliament and the Council of the EU approved the energy and climate package which sets targets for combating climate change until 2020. It focuses on three key objectives (the $3 \times 20\%$ package): (1) reducing greenhouse gas emissions, (2) promoting the use of energy from renewable sources, and (3) increasing the energy efficiency of the European Union. Subsequently, on 24 October 2014, climate and energy policies to be pursued until 2030 were agreed upon. They obliged member countries to reduce emissions in total by at least 40% by 2030 compared to 1990. In addition, the European Council approved four targets for the entire European Union in the 2030 perspective. They were revised in 2018 and, in 2020, they stated as follows:

(1) a reduction in greenhouse gas emissions by at least 55% compared to the 1990 level;
(2) 32% as the minimum share of energy from renewable sources in gross final energy consumption;
(3) increase in energy efficiency by 32.5%;
(4) completion of the EU internal energy market.

Increasing energy efficiency by lowering primary energy consumption and reducing energy imports has been identified as one of the main means of action. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, indicated that It helps to reduce greenhouse gas emissions in a cost-effective manner and, thereby, to has indicated that it is possible to reduce greenhouse gas emissions by contributing to halting climate change. The transition towards a more energy-efficient economy will also increase access to innovative technological solutions, enhance the competitiveness of European industry. It will also contribute to stimulating economic growth and creating new jobs related to energy efficiency. In addition, in November 2016, the European Commission presented the "Clean Energy for All Europeans" package, also known as the Winter Package. It sets EU targets for a global and comprehensive transition towards low-carbon economy in an attempt to mitigate climate change.

On 11 December 2019, the European Commission presented the European Green Deal (EGD). It aims to transform the European Union into a fair and prosperous political society. This strategy includes actions to, among other things: (1) enable prevention of climate change, (2) eliminate pollution, (3) protect and restore biodiversity, (4) transition to a circular economy. The EGD aims to reduce net greenhouse gas emissions to zero and minimize the relationship between economic growth and resources. The European Union is set to be the first climate-neutral continent by 2050.

Sustainable energy development of countries and regions is a broad area of scientific research [20–22]. On the other hand, few empirical and theoretical articles have been devoted to the methods of defining Sustainability Development indicators. It is possible by providing all citizens with access to "clean" energy that will be produced from renewable energy sources (RES) [23]. This has given rise to the question about how the Suitability Energy Development indicator can be measured. One such tool is the Energy Indicators for Sustainable Development (EISD) [24]. It is the result of activities carried out by the IAEA in cooperation with UNDESA, IEA, the Statistical Office of the European Communities (Eurostat) and the European Environment Agency (EEA).

This problem is indicated by M. T. García-Álvarez, B. Moreno and I. Soaresz from 2016 [25]. They proposed the Synthetic Index of Energy Sustainable Development for EU-15. It was calculated on the basis of three indicators: Security of Energy Supply, Competitive Energy Market dimension, and Environmental Protection indicators, which were then aggregated into a synthetic index. Denmark, the Netherlands, France, Portugal and the United Kingdom scored best, while Spain, Ireland, Greece, Belgium and Luxembourg-worst. They clearly showed the need for new and more effective actions, as well as better coordination of energy policies at national and EU level. Ingunn Gunnarsdottir et al. [26] provided an overview of indicators for assessing energy sustainability. They conducted an analysis and evaluation of established indicator sets for sustainable energy development (SED). A total of 57 sets of indicators were analysed to monitor progress in energy sustainability or only selected aspects of it., were described. It transpired that, with the exception of one, all indicator sets were deficient in some aspect, in particular due to the lack of transparency, lack of consideration of links between indicators, an unbalanced picture they presented, and lack of stakeholder engagement in the process of indicator development. Energy Indicators for Sustainable Development, jointly developed by many international agencies, were identified as one complete indicator. However, several flaws were found in this set. These indicators (EISD) can be used for an initial assessment and should then be adapted to the context being analyzed to ensure their usefulness. It is indicated that stakeholder participation should also be enhanced in the process of refining these indicators, ensuring a trade-off between the three dimensions. However, the experiences of many countries indicate that the EISD does not sufficiently capture the specificities of all countries, especially those with unique energy mixes e.g., the Baltic States [27] or Iceland [28]. The EISD indicators require a very large number of indicators, which causes a problem in its analysis, making it impractical and difficult to interpret [29]. In addition, EISD indicators are not aggregated, which makes them multidimensional and difficult to verify [30].

Streimikiene D., Ciegis R. and Grundey D. [28] present the use of EISD to analyze trends, set energy policy goals and monitor these goals. On their basis, recommendations for the development of sustainable energy policy in the Baltic states with the use of this indicator approach were presented. It was designed to provide information on current energy trends. Its purpose is to assist decision makers at the national level and to enable the assessment of the effectiveness of energy policy in terms of actions for sustainable development.

A method of assessing the level of energy and climate sustainability was proposed by M. Tutak, J. Brodny and P. Bindzar [30]. The assessment of indicators monitoring the implementation of Sustainable Development Goals was carried out using data from the European Statistical Office (Eurostat) for the period 2009–2018. The analysis was conducted for 27 countries, based on 14 indicators. These indicators are divided into stimulants (e.g., final energy consumption), and destimulants (e.g., greenhouse gas emissions, tons per capita, electricity prices by type of user).

2.2. COVID-19 and Sustainable Energy

The impact of the COVID-19 pandemic on energy sustainability is not insignificant. The pandemic caused a global health [31,32], social and economic [33–36] crisis. It also strongly affected real estate markets and changed the role played by housing [37–55]. Many other interesting publications in this field can be found. However, in my research, I focused on estimating the impact of COVID-19 on energy sustainability. Many researchers have attempted to estimate the impact of COVID-19 on the energy sector [56–68], inter alia in the context of the energy crisis and the increase in electricity demand [69–71].

For example, the impact of COVID-19 on the level of energy poverty in Poland was studied [72]. COVID-19 was shown to exacerbate energy poverty in Poland. The impact of the COVID-19 pandemic on electricity consumption by residential consumers was also demonstrated [73]. On average, the energy consumption of residential customers increased. Nevertheless, the peak power for these facilities during lockdown remained virtually unchanged compared to pre-pandemic values.

COVID-19 also had a not insignificant impact on stock indices associated with the alternative and the conventional energy sector [74]. It was indicated that the energy sector, as measured by the Global Alternative Energy Index (MSCI), is more resilient to COVID-19 than the conventional energy sector.

3. Materials and Methods

In order to achieve the aim of my research, I formulated the following research hypotheses:

- H1: There is a relationship between household electricity price, economic growth and innovation expenditures and CO_2 emissions between 2007 and 2021.
- H2: There is a relationship between GDP per capita, innovation expenditure, CO_2 emissions and electricity consumption (renewable and black energy–fossil fuels).
- H3: There is a relationship between energy prices, GDP per capita and renewable energy consumption before the COVID-19 outbreak (i.e., before 2019) and following the 3rd wave in 2021.

The structure of energy production was defined according to several groups described in Figure 1. Electricity production data has been aggregated into six generation types. Data was collected using EUROSTAT sources, from Embrer's website and from national sources.

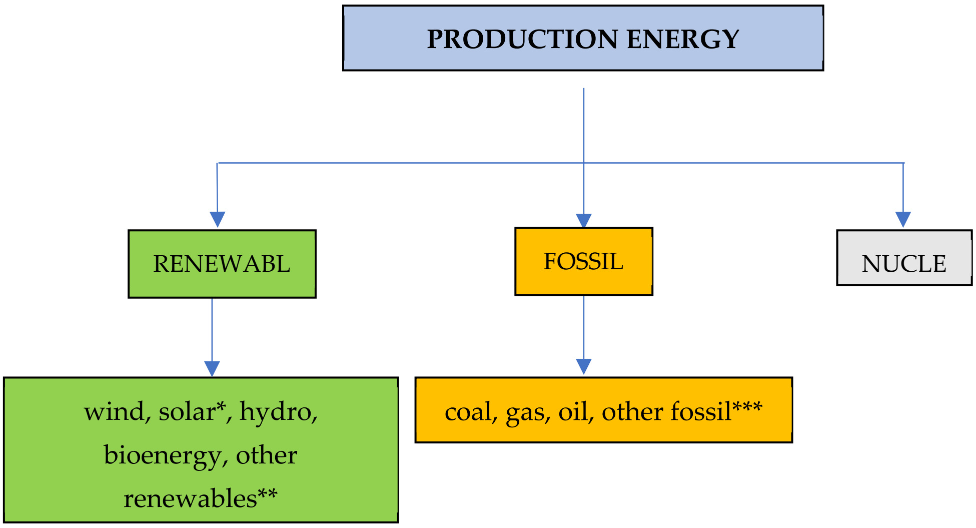

Figure 1. Structure of energy production. * The "solar" group includes all sources, including solar farms, photovoltaic cells and distributed generation. ** The "other renewables" group includes geothermal, tidal and wave power generation. *** The "other fossil" group includes sources that use raw materials: oil, petroleum products and industrial gases.

In this paper, selected indicators are comprehensively analyzed with a special focus on the impact of the pandemic on sustainable energy development. To obtain the information required for this study, I started by searching for data from recognized scientific databases such as Google Scholar, Web of Science, Scopus, journal pages (MDPI, Elsevier, Springer, etc.); the following were used as titles, abstracts and keywords in the query: sustainable energy development, households, energy price, production energy, renewables, COVID-19. At this stage, I collected relevant studies. Then, based on eligibility criteria and their availability, I identified the knowledge of indicators for energy sustainability assessment within 15 years. This allowed for a global understanding of problems associated with development. The analysis was conducted for 15 European countries. Each country is described by 9 indicators, which are also indicators of energy-climate sustainability.

In the next step, in order to create of synthetic index to assess the degree of sustainable energy development (SISED), the following data was collected [75–82]:

(1) electricity price for household consumers [MWh],
(2) GDP,
(3) CO_2 emissions,
(4) population,
(5) investment in innovation (R&D),
(6) the country's total energy production (black and renewable),
(7) production of renewable energy,
(8) production of black energy (fossil fuels).

Electricity price data was determined as follows:

- time frequency: average annual electricity price,
- consumption: Band DC: 2500 kWh < Consumption < 5000 kWh,
- taxes: excluding taxes and levies,
- currency: Euro.

As some data from 2021 is missing, it were determined using the linear approximation method. For this purpose, data from 60 months between January 2015 and December 2020 was taken into consideration.

In order to determine the impact of the analyzed factors, the structures of electricity consumption of households, innovation expenditure, changes in electricity prices and economic growth with the level of CO_2 emissions between individual European Union (EU) countries were compared using the multiobjective decision analysis (MODA) with the single attribute value function (SAVF). These methods were chosen because of some very complex issues involving multiple criteria and multiple parties that can be profoundly affected by the outcomes of decision. Multi-Objective Decision Analysis (MODA) is the decision-making process when there are very complex issues, including many criteria and many pages that can be profoundly influenced by decision outcomes. This will allow consideration and weighing of factors and tradeoffs when evaluating each alternative (in this case, quarterbacks entering the draft). The groups then discuss the combined group results to help make a decision about the recommendation. The MODA analysis I conducted consisted of ten steps, which are shown in Figure 2. These are the various stages of the research.

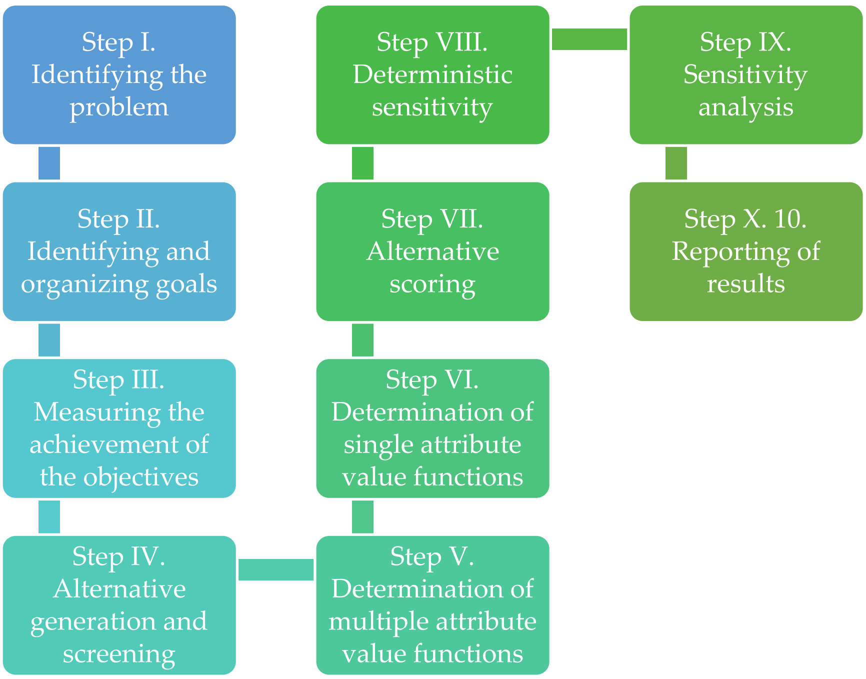

Figure 2. Ten steps of the MODA analysis.

Step I–III concerns discussing and agreeing the assessment factors. Step IV–VI concerns determining the relative importance of each factor and assigning appropriate weights to it. Step VII deals with determining the route options to be assessed. Step VIII–IX is the evaluation of each route option for each weighted factor. Step X is to discuss the results and make a decision.

Single-value attribute functions (SAVFs) are used to calculate scores for individual criteria based on raw data. The three types of SAVFs are exponential, linear, and categorical. SAVF values can be increasing or decreasing.

In order to assess the energetic sustainability of the selected European countries, the multiobjective decision analysis (MODA) was used. The analyzed data covers the period:

(1) from 2007 to 2019-before the outbreak of the COVID-19 pandemic,
(2) after the third wave COVID-19 (April 2021–September 2021).

The choice of the research period was not accidental. I focused on the third wave, because only after this period could I observe changes in the area of sustainable energy development compared to the period before the pandemic, and whether the closure of economies had an impact on this area. After the first wave of the pandemic, it has not yet been possible to conclude on its impact on energy sustainability compared to the pre-pandemic period.

The assessment of sustainable energy and climate development in the selected of EU countries was carried out in two dimensions (areas): (1) energy and climate, and (2) economic indices. These are some of the key areas for the assessment of the sustainable energy development.

All calculations were performed using the R programming language and RStudio IDE. Obtaining additional functionality of the program was possible by using additional packages, i.e., tidyverse, Cairo, Decision Analysis and rworldmap.

4. Results

4.1. Preliminary Analysis

To determine the changes from 2007 to 2019 and 2019 to 2021 in the values of the 9 indicators of energy sustainability, I conducted a comparative analysis. The results of the analysis are presented in Figure 3. 2007 has been adopted as the base year. This means that the changes of indicators (in percentage terms) have been calculated in relation to 2007. To have the first insight into the obtained data, a preliminary analysis was performed. This analysis involved standardizing the variables and developing one common scale, which was then plotted on a graph. To normalize the data, in the first step, relative percentages for 2021 were calculated. This allowed us to show the values of the variables for a relative increase or decrease. Next, all variables were plotted using a line plot. The results of the analysis are presented in the Figure 3.

Analysing the percentage changes of the studied indicators in each country (Figure 2), one will notice significant differences in this process. In terms of the use of black energy, the greatest progress was achieved by Denmark, which reduced this consumption by more than 79.43% in the examined period. The most insignificant changes in black energy consumption were achieved by Poland (−4.59%) and the Netherlands (−6.20%).

The greatest increase in electricity prices for households was observed in Greece (change of +44.89%), Finland (+38.25%) and France (+37.66%), while the smallest in Denmark (+1.27%). Interestingly, in Sweden the energy price for households decreased by −43.97% and in Poland by −13.84%.

In relation to the indicator of CO_2 emission, the greatest reduction was achieved by Greece (−36.64), Denmark (−36.6%) and Finland (−32.95%), while in Poland the reduction was only −1.53%.

With regard to the indicator of the amount of renewable energy sources in the total balance of energy production, the greatest increase in the 2007–2021 period was achieved by the UK (+565.29%) and Poland (+412.43%), while in France the share decreased by −80.6%.

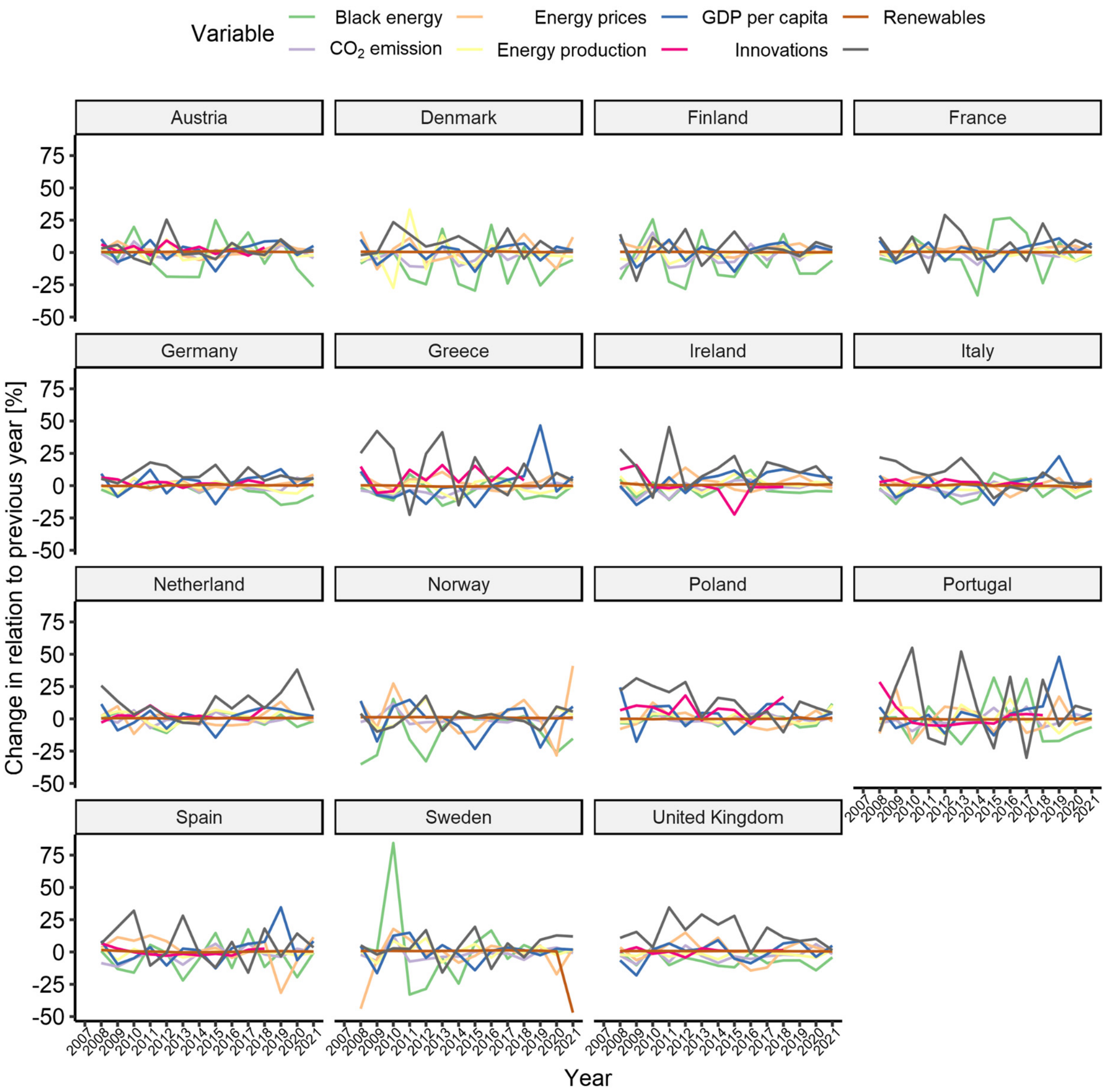

Figure 3. Relative changes in all variables used in the study.

4.2. Assess the Energetic Sustainability of the Chosen European Countries-Multiobjective Decision Analysis (MODA)

In order to propose a synthetic index to assess the degree of the sustainable energy development (SISED), the multiobjective decision analysis (MODA) was used. According to the standard MODA analysis process protocol, first the problem was defined. The overriding factor was established: it is the level of sustainable energy development in SISED. Then the two dimensions of energetic sustainability were created. These are:

(1) economic indices, and
(2) energy and climate.

Next, appropriate variables were assigned to each dimension. Economic indices included: energy price, innovations, and GDP per capita, while the energy and climate included: energy production, black energy, CO_2 emissions and the use of Renewable energy sources (Figure 4). The stimulating or de-stimulating character of the variables was also taken into account. The first group includes the following factors (the higher their value, the better):

- energy price,
- GDP per capita,

- renewables,
- innovation, R&D,

	Dimension	Variable	Direction of impact
Energy sustability	economic indices	energy price	stimulating
		innovations	stimulating
		GDP per capita	stimulating
	energy and climate indices	energy production	destimulating
		black energy	destimulating
		renewables	stimulating
		CO_2 emission	destimulating

Figure 4. Dimensions of energy sustainability and corresponding variables (green = stimulating, orange = de-stimulating).

The de-stimulating impact has been observed with respect to the following factors (the lower their value, the better):

- energy production,
- black Energy,
- CO_2 emissions.

The following step involved the determination of the single attribute value function (SAVF). To evaluate the single attribute of stimulants and destimulants, an increasing and decreasing exponential value function in this study was used

For the calculation of variable weights, the entropy weighting method was used according to these formulas:

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)} \tag{1}$$

where:

$$E_j = -k\sum_{t=1}^{m} r_{ij} ln(r_{ij}) \tag{2}$$

where:

$$k = -\frac{1}{ln(n)} \tag{3}$$

It should be noted that the values of the single attribute value function and variable weights were calculated separately for each year from 2007 to 2021, and for each country. The cumulative value of the weights is presented in Figure 5. It shows the significance of individual variables and correlations between them in the 2007–2021 period.

The diagram shows the importance of individual variables (black energy, energy production, renewables, innovations, GDP per capita, energy price, CO_2 emission) in individual MANOVA models. The analysis of the weights shows that over the course of 15 years (from 2007 to 2021), e.g., the Black energy variable was, in 2007–2011, insignificant in terms of sustainable development. It was only after 2011 that it started to gradually increase in value. This means that it was only recently that the share of black energy (as raw material) started to become important in the area of sustainable development. On the other hand, the importance of the GDP per capita variable decreased after 2016.

The indicators of innovation, renewables, energy production and CO_2 emissions are the most significant for energy sustainability in the period from 2019 until the end of the third wave of the COVID-19 pandemic. In the period between 2019 and the end of the third wave of the COVID-19 pandemic, the greatest change in terms of the importance of indicators was observed for GDP per capita and black energy, which declined in importance.

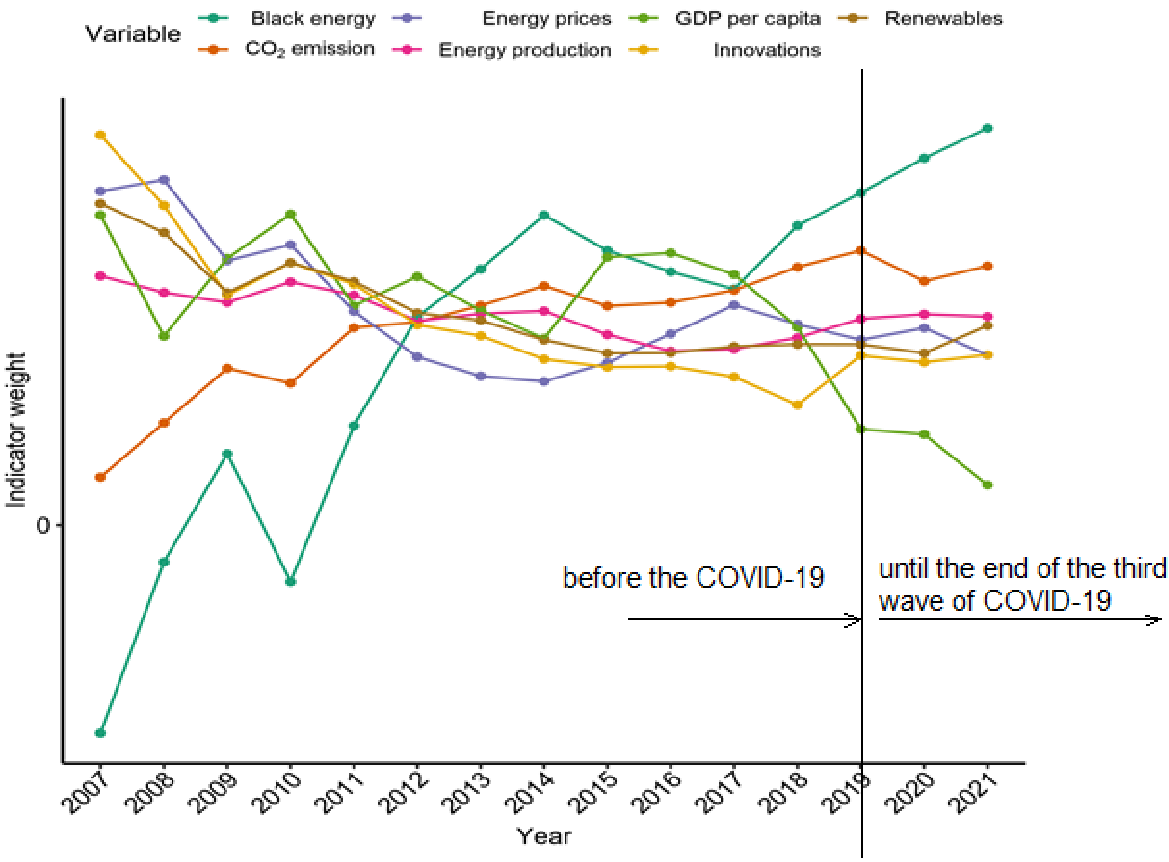

Figure 5. The variables' weights for multi attribute value functions.

Both the values obtained from exponential single attribute value functions and variables' weights were necessary to calculate the energetic sustainability index (ESi) with the use of multiple value attribution function (MAVF). This function allows taking cognisance of variables' importance for each year separately.

After calculating MAVF values, they were ranked from highest to lowest. The higher the value of the energetic sustainability index, the higher the development of the country in terms of energetic sustainability. The energetic sustainability indices and ranks are presented in Table 1.

It was found that the clear leader of the energy sustainability ranking for the entire study period (2007–2021) was Sweden (mean value: 2.73), while Ireland (mean value: 12.80) and Poland (mean value: 12.40) ranked last. Unfortunately, Poland has continued to score lowest (Rank = 15) in terms of energy sustainability since 2013. The average value of the tank index for the period 2007–2021 is presented in Table 2.

During the 2007–2021 period, the highest increase (by 8 positions) in the ranking was achieved by Denmark (from 11th in 2007 to 3rd in 2021), Finland (from 14th in 2007 to 7th in 2021), and Ireland (from 15th in 2007 to the 8th in 2021), which means an increase by 7 positions in the ranking.

Poland, on the other hand, has seen the greatest descent, from 9th in 2007 to 15th in 2021, which is a drop of 10 places in the ranking. In the remaining countries, changes remained within the range of 2 to 3 positions.

Overall, each of the EU countries analysed recorded a change in the value of energy sustainability indicators over the entire 2009–2021 period. Between 2018 and 2021 (until the end of the third wave of COVID-19), the largest increase in the energy sustainability ranking was observed in Finland (+7) and Spain (+5), while the largest decrease was observed in Germany and the UK (−6).

Table 1. Energy Sustainability Development (SISED) indices and ranks.

Country	2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		2020		2021	
	Es	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**	**Es**	**R**
Austria	0.63	3	0.61	5	0.60	3	0.58	4	0.59	2	0.62	1	0.64	1	0.66	1	0.64	1	0.64	1	0.62	2	0.64	1	0.43	5	0.42	6	0.46	5
Denmark	0.38	11	0.36	10	0.43	10	0.51	9	0.48	6	0.57	4	0.54	5	0.57	4	0.62	2	0.60	2	0.62	1	0.58	2	0.54	2	0.59	3	0.56	3
Finland	0.29	14	0.35	12	0.33	13	0.27	15	0.34	15	0.4	11	0.38	13	0.41	11	0.42	11	0.40	12	0.40	11	0.37	12	0.39	9	0.40	8	0.42	7
France	0.67	2	0.67	3	0.62	2	0.65	2	0.59	4	0.56	5	0.54	6	0.51	5	0.49	7	0.50	7	0.49	6	0.49	6	0.46	4	0.46	4	0.48	4
Germany	0.39	10	0.35	11	0.43	11	0.42	12	0.43	11	0.41	10	0.42	10	0.45	8	0.45	9	0.45	9	0.46	9	0.48	7	0.32	13	0.31	13	0.31	13
Greece	0.46	9	0.39	9	0.42	12	0.55	5	0.44	9	0.40	12	0.39	12	0.36	14	0.39	14	0.39	13	0.40	12	0.37	13	0.34	12	0.32	12	0.31	12
Ireland	0.20	15	0.15	15	0.32	14	0.32	13	0.36	13	0.36	15	0.38	14	0.38	13	0.40	12	0.38	14	0.38	14	0.38	11	0.37	11	0.39	10	0.40	8
Italy	0.50	8	0.46	8	0.51	6	0.52	8	0.46	7	0.48	7	0.49	7	0.47	7	0.48	8	0.50	6	0.49	7	0.46	9	0.38	10	0.38	11	0.37	11
Netherland	0.29	13	0.24	14	0.28	15	0.30	14	0.35	14	0.38	14	0.40	11	0.41	10	0.42	10	0.41	11	0.40	10	0.43	10	0.26	14	0.27	14	0.27	14
Norway	0.57	6	0.61	4	0.56	5	0.46	10	0.52	5	0.56	6	0.58	2	0.60	2	0.56	4	0.54	4	0.52	5	0.52	5	0.52	3	0.60	2	0.59	1
Poland	0.58	5	0.51	6	0.51	8	0.55	7	0.43	12	0.40	13	0.36	15	0.34	15	0.36	15	0.35	15	0.35	15	0.33	15	0.26	15	0.26	15	0.23	15
Portugal	0.71	1	0.68	2	0.59	4	0.75	1	0.67	1	0.59	2	0.56	4	0.50	6	0.50	5	0.50	8	0.48	8	0.48	8	0.42	6	0.43	5	0.43	6
Spain	0.52	7	0.50	7	0.51	7	0.55	6	0.45	8	0.43	8	0.44	8	0.40	12	0.40	13	0.43	10	0.40	13	0.36	14	0.39	8	0.41	7	0.40	9
Sweden	0.62	4	0.73	1	0.65	1	0.61	3	0.59	3	0.57	3	0.57	3	0.58	3	0.56	3	0.55	3	0.55	4	0.55	3	0.56	1	0.61	1	0.56	2
UK	0.35	12	0.34	13	0.44	9	0.44	11	0.44	10	0.42	9	0.43	9	0.43	9	0.50	6	0.52	5	0.55	3	0.54	4	0.40	7	0.39	9	0.40	10
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
	0.48	0.16	0.46	0.17	0.48	0.12	0.5	0.13	0.48	0.10	0.48	0.09	0.47	0.09	0.47	0.09	0.48	0.09	0.48	0.08	0.47	0.09	0.46	0.09	0.40	0.09	0.42	0.11	0.41	0.11

Table 2. The average value of the Rank index for the 2007–2021 period.

Countries	Average Rank Index Value in the Period 2007–2021	Change in the Ranking Position between 2007 and 2021	Change in the Ranking Position between 2018 (Prior to COVID-19) and 2021 (Until the End of the Third Wave of COVID-19)
Austria	2.73	−2	−4
Denmark	4.93	8	−1
Finland	11.60	5	7
France	4.47	−2	2
Germany	10.40	−3	−6
Greece	11.33	−3	1
Ireland	12.80	7	3
Italy	8.0	−3	−2
Netherland	12.53	−1	−4
Norway	4.27	5	4
Poland	12.40	−10	0
Portugal	4.47	−5	2
Spain	9.13	−2	5
Sweden	2.53	2	1
UK	8.40	2	−6

After that, the countries were divided into four groups considering the mean and standard deviation of SISED for each year separately. These are the following levels of sustainable energy development: group 1-safe level, group 2-medium level, group 3-warning level, group 4-dangerous level. Based on the analysis of the entire 2007–2021 period, it was found that Sweden and Denmark achieved the safe level (group 1) of sustainable energy development. At the other end of the spectrum, only Poland classified as having the dangerous level (group 4). The remaining countries fell into groups 2 and 3. Year-to-year changes in energy sustainability per country can be traced in Figures 6–9.

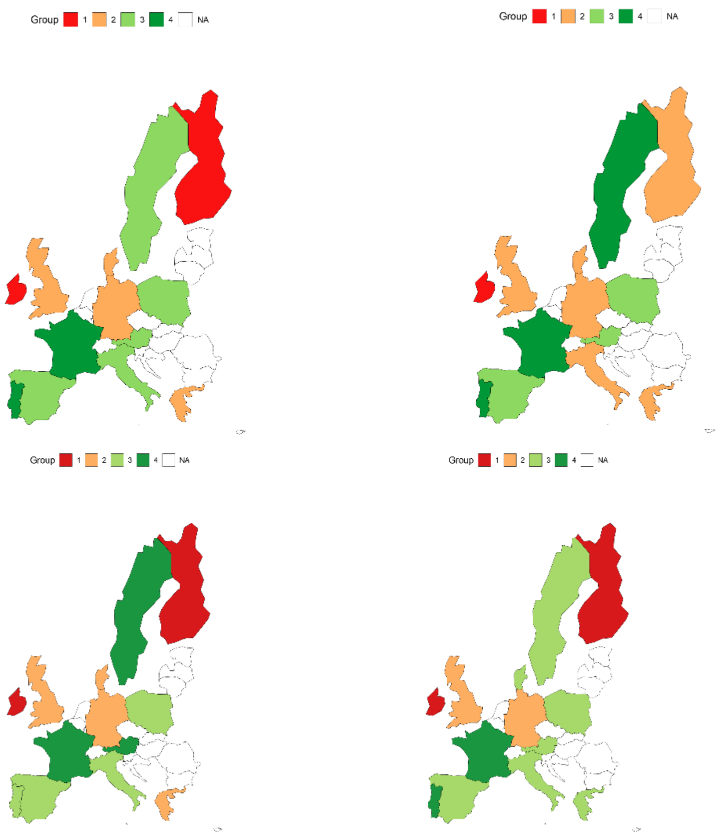

Figure 6. SISED for individual EU countries in 2007–2010.

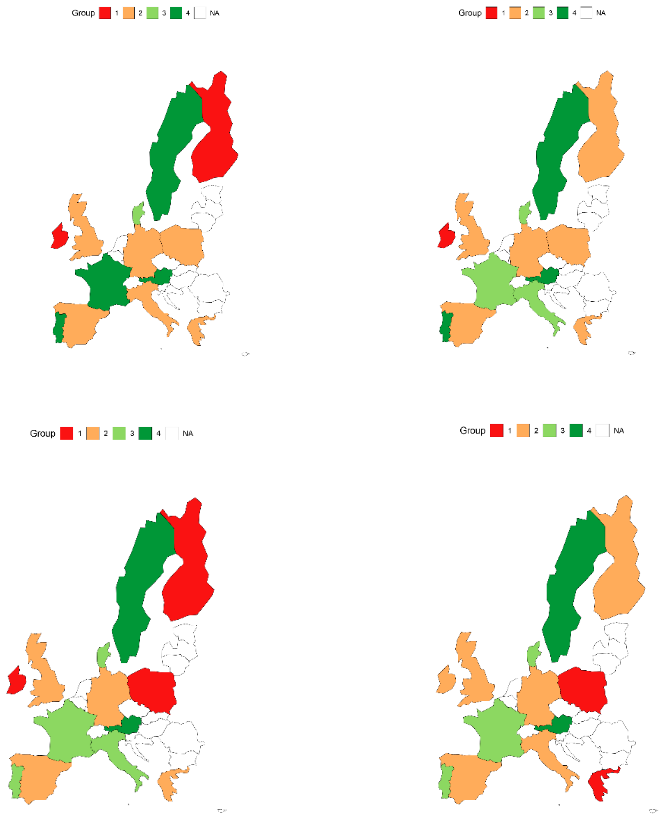

Figure 7. SISED for individual EU countries in 2011–2014.

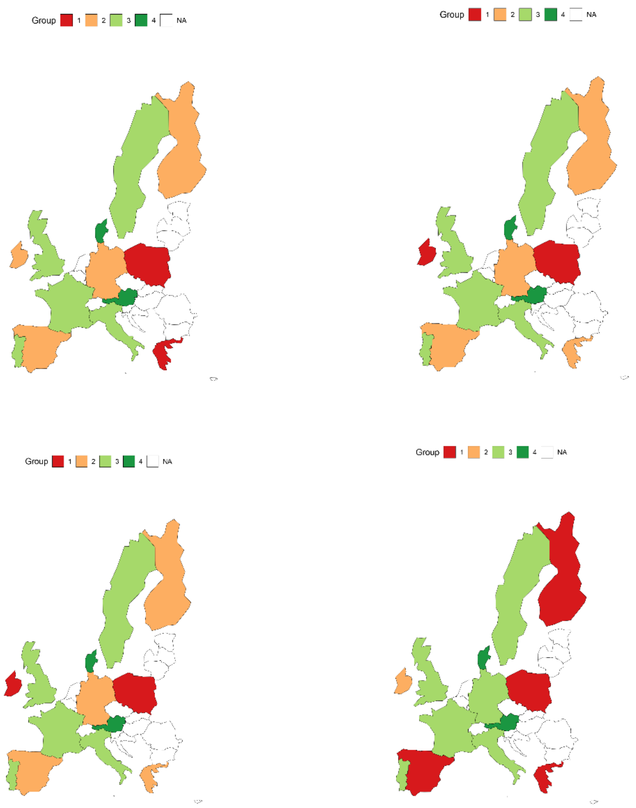

Figure 8. SISED for individual EU countries in 2015–2018.

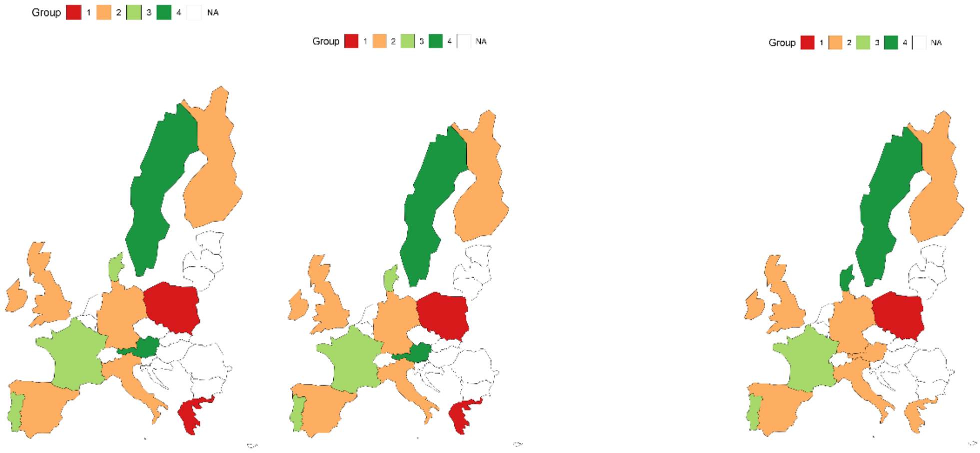

Figure 9. SISED for individual EU countries in 2019–2021.

Finally, in order to understand the influence of used variables on the overall Energy Sustainability score, the MAVF breakout plot was used. It divides the overall Energetic Sustainability score for each country (15 countries) into parts because of the partial variables score. The results of the analysis are presented in Figures 10–13.

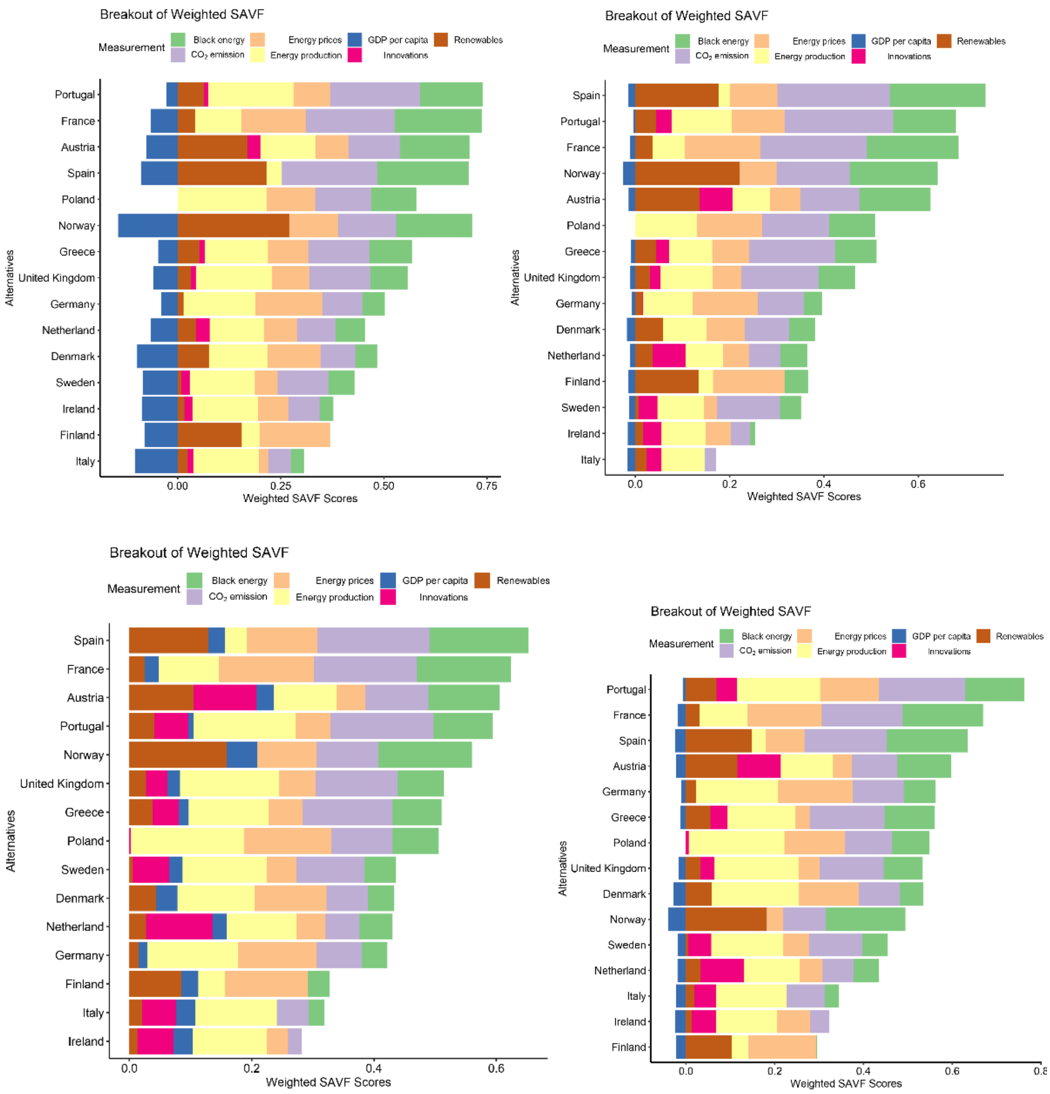

Figure 10. Influence of used variables on the overall SISED for all EU countries in 2007–2010.

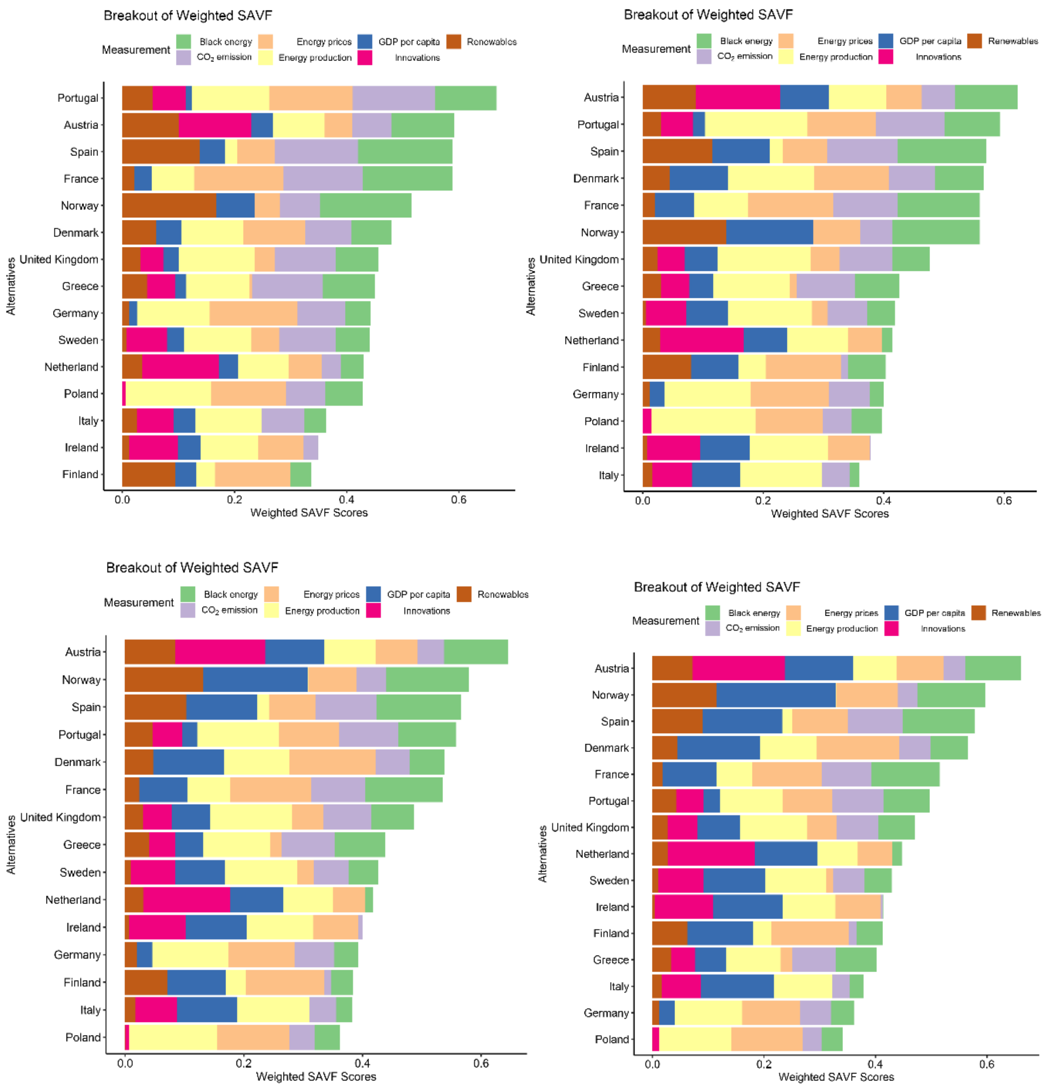

Figure 11. Influence of used variables on the overall SISED for all EU countries in 2011–2014.

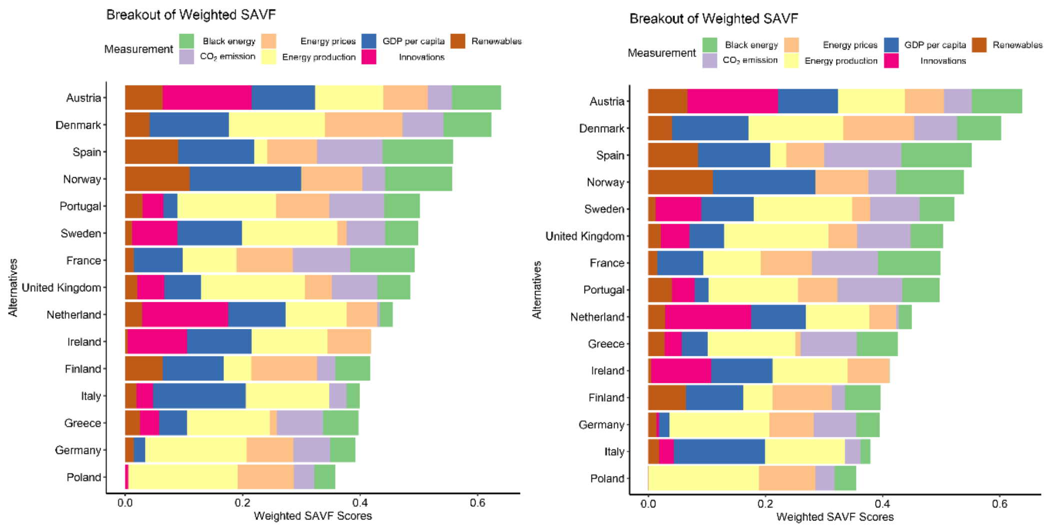

Figure 12. *Cont*.

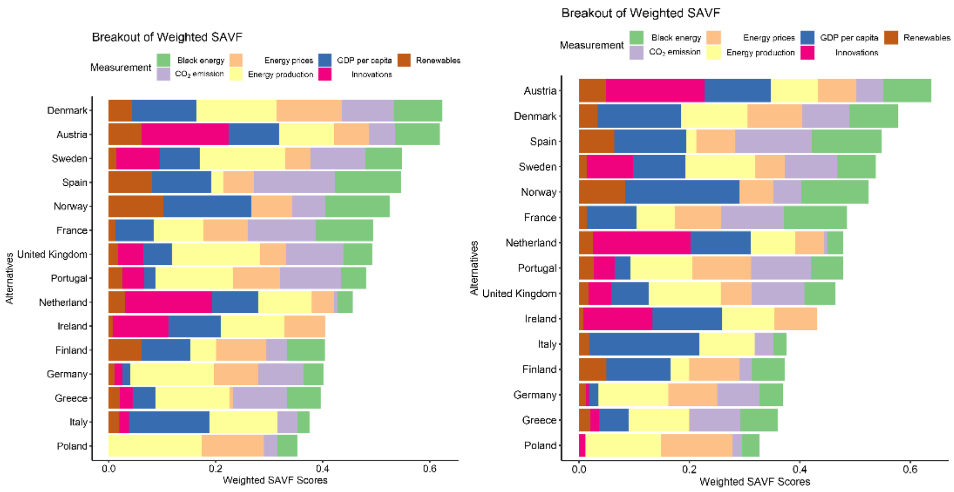

Figure 12. Influence of used variables on the overall SISED for all EU countries in 2015–2018.

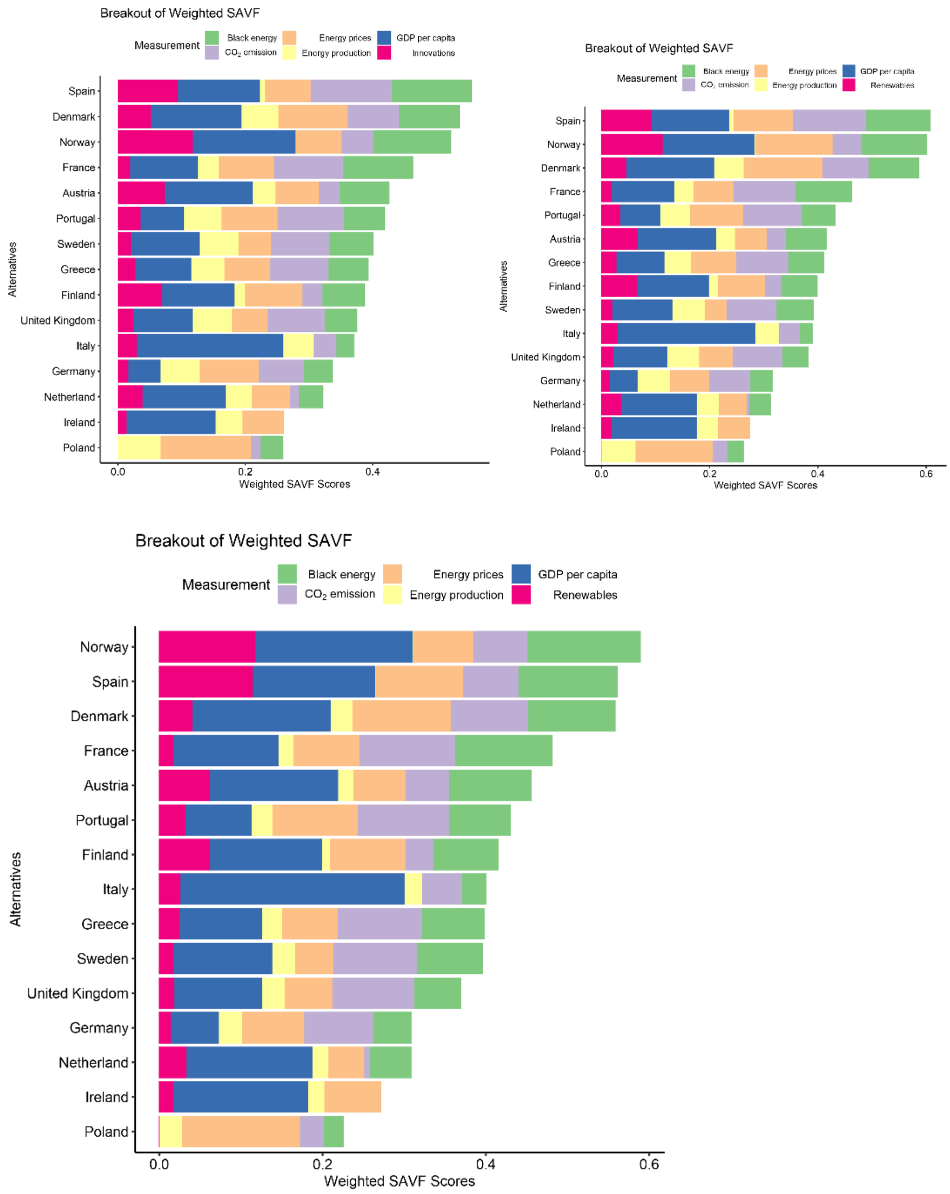

Figure 13. Influence of used variables on the overall SISED for all EU countries in 2019–2021.

The value breakout graph allows for a quick and easy comparison of how each attribute affected the alternatives.

5. Discussion

By 2030, coal consumption is projected to fall by 70% compared to 2015, and renewable sources will account for 60% of all energy generation. Some Member States have committed to phasing out coal by setting specific dates in their national energy and climate plans: Sweden and Austria in 2020, Portugal in 2021, France in 2022, Italy in 2025, Ireland in 2025, Greece in 2028, the Netherlands, Finland, Denmark, Spain in 2030, Germany in 2038. Germany assumes that, in 2030, the share of RES in its gross consumption forecast at 580 TWh will stand at 65%. In order to achieve this target, RES capacity of approximately 200 GW will need to be installed. France has set a target of 40% share of energy from RES in total electricity consumption by 2030. This target will be attained by generating 101–113 GW of installed RES power in 2028. Spain plans to generate 74% of electricity from renewable sources by 2030 (by 2050, RES is to represent 100%). Between 2021 and 2030, 59 GW of RES units are expected to be installed, bringing the total installed capacity of these sources to 122.7 GW.

The conducted research allowed the hypotheses to be verified. Hypothesis H1 was confirmed: There is a relationship between household electricity price, economic growth and innovation expenditure and CO_2 greenhouse gas emissions in the 2007–2021 period: the higher the household electricity price, economic growth and innovation expenditures, the lower the CO_2 greenhouse gas emissions.

On the other hand, hypothesis H2 was only partially confirmed: There is a relationship between GDP per capita, innovation expenditure, CO_2 emissions and electricity consumption (both renewable and black). The correlation depends on the analyzed time interval. From 2007 to 2012 it was minor, later-until 2019-it was moderate, while after the third wave of pandemic (2021) the correlation was strong. In contrast, the dependence of GDP per capita on other factors has decreased significantly since 2018 and in the period following the third wave of the pandemic in 2021 it became minor. This is probably due to the ongoing efforts to promote renewable energy sources, along with considerable EU and national subsidies for their construction.

Hypothesis H3 was also confirmed: A relationship can be found between energy price, GDP per capita and renewable energy consumption both before the COVID-19 pandemic (i.e., until 2019) and after the 3rd wave in 2021. The analysis shows that the amount of black energy generated by a country is inversely proportional to its level of sustainability. It is noticeable that the relationship between black energy and GDP is quite strong before the COVID-19 outbreak. However, it changed after the third wave of the pandemic: the relationship is considerably weaker and a decreasing trend is revealed. Although, since 2015, the CO_2 production trend was upward, it reversed during the pandemic and the relationship between black energy and CO_2 emissions started to become weaker.

A strong correlation between economic growth and CO_2 emissions across the examined countries and during this period was observed. No evidence was found of the impact of changes in the structure of electricity consumption of households on the level of CO_2 emissions and the impact of economic growth on electricity consumption of households after the third wave of the COVID-19 pandemic. This is important because CO_2 emissions data reveals a decline and re-emergence of emissions during the COVID-19 pandemic.

The conducted analysis of sustainable energy development showed a growing importance of the black energy variable in the achievement of sustainable development. This relationship has been observed since 2012. From 2017 to 2021, an almost linear increase is observed. This means that in the period until the end of the third wave of the COVID-19 pandemic (i.e., until April 2021), is no change in this relationship.

As a result of the presented MODA analysis, it was possible to assign countries to four groups according to their level of energy development (SISED), where group 1 means the highest SISED index, and 4-the lowest SISED index.

Each of the 15 European countries analyzed recorded a change in the value of energy sustainability indicators over the entire 2009–2021 study period. Between 2018 and 2021 (until the end of the third wave of the COVID-19 pandemic), the largest rise in the energy sustainability ranking was observed in Finland, while the largest decrease was observed in Germany and the UK (−6). This large decrease could be attributed to building insulation, reduced investment in innovation and the lockdown.

There is no doubt that the achievement of sustainable energy development goals requires the coordination of all policies influencing the development and use of energy.

The EU should continue to support its Member States, including those included in the 1st category. Following the third wave of the COVID-19 pandemic (2021), the least developed countries in terms of SISED are: Poland (15th position), Ireland (14th), the Netherlands (13th), and Germany (12th). It can be accounted by the fact that the Polish electricity sector is dependent on traditional fuel. An interesting result in Poland is the observed change in the structure of the impact of the energy price factor, which increased in relation to the energy production factor.

The most developed countries are the following: Norway (1st), Spain (2nd), Denmark (3rd) and France (4th). These values were the same in the period prior to the COVID-19 pandemic (in 2019). However, in the period before the COVID-19 pandemic (in 2019), there was a slight shift among the most developed countries: Spain (1st position), Denmark (2nd), Norway (3rd) and France (4th). An interesting result is the rise of Italy in terms of SISED, from the 11th to the 8th position after the third wave of the COVID-19 pandemic (2021), which is due to the greater per capita impact of the GPB factor than the energy production factor.

Despite the observed change in the structure of electricity consumption and the increased electricity consumption of households during the the COVID-19 pandemic, it did not significantly affect CO_2 emissions.

Regarding the indicators analyzed, a similar study by García-Álvarez et al was conducted [25]. They also focused on the energy sustainability index for selected EU-15 countries. However, they used different methods. Taking into account the above limitations, I attempted to compare the rankings for the EU-15 countries. The study analyzed here presents results covering the period 2002–2012, while my study includes data from 2007–2021. García-Álvarez et al. [25] grouped the EU-15 countries into three subgroups of five countries each, with high, medium and low rankings. Denmark, the Netherlands, France, Portugal, and the United Kingdom performed best in 2012. In my study, the group of countries with highest results in 2012 includes Austria, Portugal, Sweden, and Denmark.

However, in terms of indicators used and the research methodology, a similar study was conducted by M. Tutak, J. Brodny and P. Bindzar [31]. They presented their sustainable energy index for the EU-27 measured from 2009 to 2018. Research tools they used are similar to those applied in my study. According to the results of their study, [31] in which they grouped the EU-27 Member States into four subgroups (group 1-safe level, group 2-medium level, group 3-warning level, group 4-dangerous level), Sweden, Denmark, France performed best in 2018. According to my study, this group included Sweden, Denmark, and Austria, which proves that the results are consistent and confirms the usefulness of the proposed synthetic indicator of energy sustainability (SISED).

6. Conclusions

The article shows how the synthetic index of sustainable energy development (SISED) can be used for the analysis of trends in the development of the energy sector of EU countries in terms of sustainable development. This can be helpful in defining sustainable energy development goals in line with those contained in national and EU policies. Its application will also contribute to the assessment of the progress towards sustainable energy development and to defining new political measures necessary to achieve these goals.

The SISED index, among others, is used to compare data between countries in the areas of energy, environment and climate or economy. The SISED index allows data to be compared across countries in the areas of energy, environment, climate and economy, to show how they are interrelated, to assess and analyze trends, and to review policies [21,24,27,30]. These indicators allow stakeholders to assess their own progress toward energy sustainability and chart their own social and political course toward greater achievements in the area of energy.

The COVID-19 pandemic has brought certain changes in electricity consumption. It has also demonstrated the importance of a flexibility electricity system and its ability to balance supply and demand. It is crucial for the development of future low-emission power systems, which are based on increasingly variable supplies of electricity from RES. In this context, it is paramount to increase R&D expenditure in order to implement new solutions, including the possibility of increasing the energy storage capacity.

The research confirms that policy makers must act without delay and provide financial and legal means to accelerate the ongoing energy transition, which must be strengthened. In addition, developing a low-carbon economy requires ensuring that the energy system has the flexibility to move away from fossil fuel-based energy.

It is also proposed to introduce measures at the level of creating national and regional policies [81,83]. In managing change aimed at creating low-emission economies, the following actions are proposed:

(1) adjusting existing policies for the transition to a low-carbon economy,
(2) involving governmental and non-governmental institutions in the implementation of initiatives related to the use of renewable energy sources,
(3) creating appropriate tools and financial incentives for households to replace fossil fuel devices with low carbon devices.
(4) creating policies with incentives and preferential conditions, the use of renewable energy sources instead of black energy.

To this end, it is essential to involve various stakeholders in the transition to this economic model and to ensure that the UN Sustainable Development Goals are met. Future research should, therefore, support decision makers in the rapid implementation of appropriate measures, and this requires expanded collaboration among researchers representing different scientific disciplines. There is no doubt that the COVID-19 pandemic has also accelerated the implementation of changes in European energy systems to combat climate change.

The presented synthetic SISED indicators could be further refined in the context in which they are to be used in order to ensure their relevance and usefulness for policies. This would involve introducing more parameters to be investigated to take into account the specific context of the examined country and to ensure a balance in the representation of sustainable energy performance results.

There were some limitations in the studies related to the lack of some data, which were supplemented by approximation. In future research, attempts should be made to evaluate the proposed index in comparison with other European Union countries.

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