energies

Article

An Analysis of the Use of Energy from Conventional Fossil Fuels and Green Renewable Energy in the Context of the European Union's Planned Energy Transformation

Katarzyna Chudy-Laskowska * **and Tomasz Pisula**

The Faculty of Management, Department of Quantitative Methods, Rzeszow University of Technology, 35-959 Rzeszow, Poland
* Correspondence: kacha877@prz.edu.pl; Tel.: +48-604077448

Abstract: Over the past few years, considerable emphasis has been put on decarbonization, which, in the context of the recent events in Europe, proves that mixing energy sources is the best strategy. This article discusses ways in which individual EU member states manage their energy source diversification, while comparing their levels of fossil fuels and renewable energy sources (RESs) usage. The research data was acquired from the Eurostat website and comprises of 15 indicators describing the use of energy both from conventional and renewable sources in the European Union, in 2019. The study employs taxonomical methods, such as ranking and cluster analysis. The authors put forward a hypothesis that EU member states approach the use of energy resources in several ways. There are countries which take advantage of both traditional and renewable sources (Netherlands, Germany, Austria, and Italy). However, there is a group of states that relies on a single energy source and exclusively uses either traditional (Poland) or renewable energy resources (Sweden, Finland). The analyses enabled the isolation of country clusters with similar activities and energy strategies.

Keywords: European Union; sustainable energy development; energy transformation; energy strategy; taxonomical analysis; ranking; TOPSIS method

check for updates

Citation: Chudy-Laskowska, K.; Pisula, T. An Analysis of the Use of Energy from Conventional Fossil Fuels and Green Renewable Energy in the Context of the European Union's Planned Energy Transformation. *Energies* **2022**, *15*, 7369. https://doi.org/10.3390/en15197369

Academic Editors: Surender Reddy Salkuti and Behnam Zakeri

Received: 1 September 2022
Accepted: 4 October 2022
Published: 7 October 2022

1. Introduction

Renewable energy sources, including wind, solar, hydroelectric, ocean thermal, geothermal, biomass, and biofuels, constitute an alternative to fossil fuels and contribute to reductions in greenhouse gas emissions, energy source diversification, and the decreasing dependency on volatile and unstable fossil fuel markets, especially the oil and gas markets. The EU legislation concerning the promotion of renewable energy sources has significantly evolved over the past fifteen years. Moreover, the issue has, considering the recent war in Ukraine, become even more evident owing to certain EU member states' overwhelming reliance on Russian gas and coal supplies.

The European Green Deal sets out guidelines on how to make Europe the first climate-neutral continent by 2050 and provides the most comprehensive package of measures enabling Europe's inhabitants and businesses to benefit from a sustainable ecological transformation. The use of renewable sources based energy offers many potential rewards, including lower greenhouse gas emissions, diversified energy supplies, and the reduced dependency on fossil fuel markets (especially the oil and gas markets). The growth of renewable energy sources in the EU can also stimulate increases in employment by creating jobs in the green technology sector. The share of energy from renewable sources in the EU has nearly doubled from 2004 to 2018, rising from 9.6% in 2004 to 18.9% by 2018. EU member states were obliged to set national energy targets and draw up their 10-year national energy and climate plans (NECPs) as part of the "Horizon 2030" programme. In 2018, Sweden was the European leader in sourcing renewable energy, with more than half (54.6%) of its energy coming from renewable sources. Consequently, Sweden was markedly ahead of Finland (41.2%), Latvia (40.3%), Denmark (36.1%), and Austria (33.4%). At the bottom of the ranking were countries with the lowest share of renewable energy, namely the Netherlands (7.4%), Malta (8.0%), Luxembourg (9.1%), and Belgium (9.4%).

Analyses of consumption patterns of electricity generated from fossil fuels, renewables, and nuclear sources over the 16 years of the enlarged EU (2005–2020), sheds more light on the issue. Figure 1 presents the percentage shares of electricity consumption in EU member states in 2020, by source.

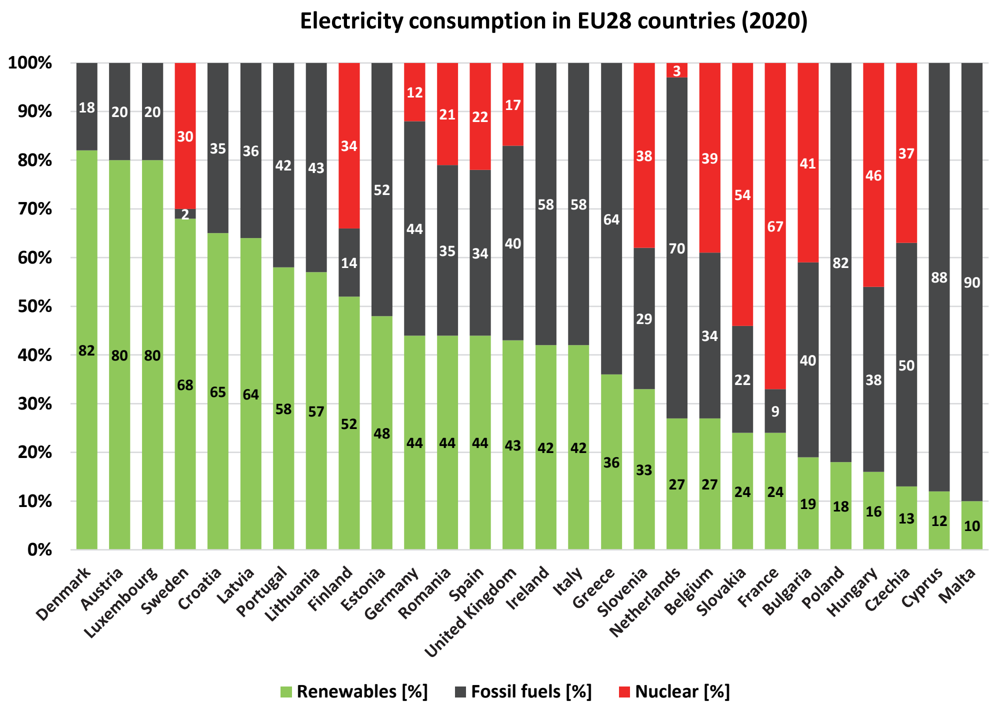


Figure 1. Electricity consumption in the EU countries from major energy sources in 2020. Source: https://ourworldindata.org/grapher/elecmizbar?time=2020&country=AUT~CYP~CZE~DNK~BGR~LUX~HRV~EST~FIN~FRA~DEU~GRC~HUN~ITA~LVA~LTU~GBR~SWE~SVK~SVN~POL~NLD~MLT~PRT~ESP~IRL~BEL~ROU (accessed on 2 July 2022).

While a clear trend for the majority of EU countries to grow their share of electricity consumed from renewable sources is noticeable, a distinctive drop in the share of electricity consumed from conventional fossil fuel sources and nuclear power plants has been witnessed, over the period.

In 2005, the mean annual percentage consumption of electricity from fossil sources (coal, oil, gas) in the EU countries was 61%, dropping to 42% in 2020. As many as 17 member states were, as of that time, still using 50% or more electricity from conventional fossil sources, of which 11 (Malta, Cyprus, Estonia, Poland, United Kingdom, Luxembourg, Ireland, the Netherlands, Greece, Italy, Portugal) consumed 75% or more non-renewable energy. The leaders, Malta and Cyprus, which obtained 100% of their electrical power from conventional sources, as well as Estonia and Poland, in which 99% and 98% of their energy use, respectively, was based on conventional fuels. In 2020, there were only eight countries with a 50% or higher share of electricity consumed from fossil sources, while barely three countries (Malta 90%, Cyprus 88%, Poland 82%) had a share of 75% or higher. The greatest decrease in the share of electricity consumption sourced from fossil sources over the 16-year period was reported in countries such as Luxembourg (by 74%, from 94% to 20%), Denmark (by 55%, from 73% to 18%), and Estonia and Portugal (by 47% and 41%, respectively). Two countries reported a rise in the share of electricity from such sources, namely Lithuania (a 19% increase from 24% in 2005 to 43% in 2020) and Latvia (a 6% increase from 30% to

36%). Other EU member states rolled back their share of fossil fuels in power generation by between 2% and 35%.

A similar downward trend was observed for the electricity generated from nuclear sources in the EU. The tendency reveals a gradual departure from electrical power from nuclear power plants for internal consumption needs. The mean annual percentage share of electricity consumed, in 2005, from nuclear sources in the EU was 21% (highest-ranking countries included France (79%), Lithuania, whose nuclear energy production was abandoned altogether in 2020, (73%), and Slovakia and Belgium (57%)). A distinctive decrease in the aforementioned share consumption is observable over the 16-year period in the vast majority of EU countries. The share percentage was, in 2020, only 16% (a 5% drop) for the EU member states. The share decline was observed in 10 countries that relied more on nuclear energy. The greatest rollbacks were reported in Lithuania (73%), Belgium (17%), Sweden (16%), Germany (15%), and France (12%). However, there were also five countries, who were beneficiaries of electricity from nuclear power plants, where their share had increased, namely Romania (11%), the Czech Republic and Hungary (7%), Spain (2%), and Finland (1%).

The EU has, for over a decade, been gradually moving away from conventional fossil fuel-based energy and nuclear power (in line with the Green Energy strategy), thus resulting in an increased share participation of renewables in the structure of electricity consumption from various sources. In 2005, the mean share of renewable sources-based electricity in the overall electricity consumption in EU countries, was merely 18%, while in 2020, it had grown to as much as 42% (an increase of 24%, i.e., the doubling of its share participation). In early 2005, there were only eight countries with the share of renewable sources-based electricity consumption that was 20% or higher, but with only four countries (Latvia, Austria, Croatia, and Sweden) where the share was 50% or more. The highest percentages were reported for Latvia (70%) and Austria (63%). By 2020, there were 22 countries in which the share of electricity generated from such sources was at least 20%, but as many as nine countries (Denmark, Austria, Luxembourg, Sweden, Croatia, Latvia, Portugal, Lithuania, and Finland) where the share was at least 50%. The share participation was exceptionally high (over 80%) in three countries, namely Denmark (82%), Austria, and Luxembourg (80%). An increase in the share of renewable sources-based electricity consumed can be observed in all countries except for Lithuania, where the share dropped by 6%, from 70% to 64%. The increase was considerably high—more than 50%—in such countries as Luxembourg (by 74%, from 6% to 80%), Denmark (by 55%, from 27% to 82%), and Lithuania (by 54%, from 3% to 57%). In nine other countries, Estonia, Portugal, the United Kingdom, Ireland, Germany, Spain, Italy, Greece, and Belgium, the share rose by about 20% to 50%. However, the expansion was much more limited despite being noticeable (by 9% to 20% in 15 countries. Member states, in which the share of renewable sources-based electricity was still very low (less than 20%) included Malta (only 10%), Cyprus, the Czech Republic, Hungary, Poland, and Bulgaria, with shares of 12%, 13%, 16%, 18%, and 19%, respectively.

The detailed shares of the individual energy sources in total electricity generated in EU countries in 2020 are shown in Figure 2. A detailed analysis of the share participation of the energy sources discussed in this study reveals that countries whose dominant (at least 50% participation) source of electricity is from conventional fossil sources. These countries include Poland and the Czech Republic, where coal contributes 68% and 39%, respectively, of the energy production, Cyprus and Estonia with 88% and 51%, respectively, and which was attributed to oil, Malta, 87%, the Netherlands, 59%, Ireland, 51%, Italy, 48%, and Greece, 40%, who relied on natural gas.

Countries in which a significant (at least 50%) electricity generation is based on renewable sources include Denmark (57% of renewable energy generated from wind power, and 20% from other less common renewable sources), Austria (61% of renewable energy from hydrological sources, and a 10% significant share of energy from wind power), Luxembourg (30% from other renewable sources, 29% from wind energy, and 13% from solar energy, the highest generation in the entire EU). Other countries worthy of note in this group of countries are Sweden with 44% and 17% of renewable energy from hydrological and wind sources, respectively, Croatia with a considerable share of renewable energy from hydrological (43%) and wind sources (13%), Latvia with a significant share of its renewable energy from hydrological (46%) and other renewable sources (15%), Portugal with a sizeable share of renewable energy generated from wind (24%) and hydrological sources (23%), Lithuania with 34% of renewable energy from wind and 13% from other, less common renewable energy sources, as well as Finland with a 23% share of renewable energy generated from hydrological sources, 15% from wind, and 17% from other renewables.

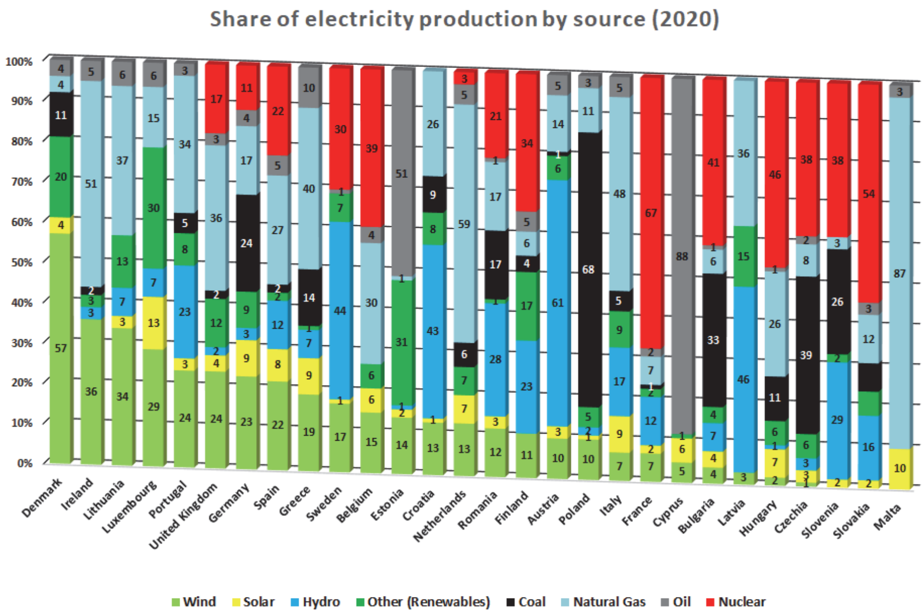


Figure 2. Share of the electricity production in the EU countries by energy source in 2020. Source: https://ourworldindata.org/grapher/share-elec-by-source (accessed on 2 July 2022).

The Table 1 presents a brief history of the EU's activities in promoting and managing the transition from fossil fuels to renewable energy as sources of electricity.

Table 1. Measures intended to boost the share of renewable energy sources in the EU countries.

Date	Activity
April 2009	It was decided that by 2020, 20% of the overall energy consumed in the EU must be sourced from renewable sources. As for the transport sector, member states agreed to attain a 10% share of fuels from renewable sources. Mechanisms to be applied by countries to reach the set targets were also specified, including support systems, common projects, and cooperation between the member states, as well as sustainable growth criteria with regard to biofuels. National renewable energy targets for individual countries to be reached by 2020, were also set, taking into account their starting points and overall renewable energy source potential (from a 10% share of renewables in Malta to 49% in Sweden). Each EU country stated how it intended to attain the individual targets and had to draw up a general action plan [1].
November 2016	The European Commission published the "Clean Energy for All Europeans" package [2].

Table 1. *Cont.*

Date	Activity
December 2018	An amended directive on renewable energy sources [3], as part of the "Clean Energy for All Europeans" package was enacted. The package was aimed at maintaining the EU's position of the global leader in renewable energy sources and assisting the EU in the fulfilment of its emission reduction obligations under the Paris Agreement [4]. The directive has been effective since 2018. A legally binding goal was set, according to which, by 2030 at least 32% of the final energy consumed in the EU should come from renewable sources. In addition, a clause was included allowing the goal to be increased by 2023. EU member states were required to put forward their national energy goals and develop 10-year national energy and climate plans under the "Horizon 2030" programme.
December 2019	The Commission issued the European Green Deal communication [5]. It detailed methods for making Europe a climate-neutral continent by 2050 through the supply of affordable and secure energy.
December 2021	In the package detailing the implementation of the European Green Deal, the European Commission proposed an amendment to the directive on renewable energy sources [6], in order to align its renewable energy target with the new climate goals. The Commission suggested raising the renewable energy source target to 40%. Talks on the energy policy framework for the period after 2030 are under way.
July 2021	The Commission published a new agenda entitled: "Fit for 55: delivering the EU's 2030 Climate Target on the way to climate neutrality" [7]. The review of the renewable energy sources directive proposed an increase in the binding renewable energy share target in the EU's energy basket by up to 40%.

Source: Study based on published EU documents.

Figure 3 shows the national renewable energy targets which the member states agreed to achieve by 2020. However, not all countries were successful in reaching their goals.

Figure 3. Renewable energy share in the total energy consumption in 2020 vs. the targets set. Source: Eurostat [8,9].

The European Green Deal focuses on three main objectives with regard to the transition to clean energy. To this end, seven main goals were set by the Commission (Table 2).

Table 2. "Green Deal" objectives and goals.

Objectives	Main Goals
1. Providing affordable and secure energy supplies in the EU. 2. Creating a fully integrated, interconnected digitalised EU energy market. 3. Prioritizing energy efficiency, improving energy performance of buildings, and developing an energy sector based largely on renewable sources.	1. Building interrelated energy systems and better integrated networks supporting renewable energy sources. 2. Promoting innovative technology and modern infrastructure. 3. Increasing energy efficiency and promoting eco-projects. 4. Cutting emissions in the gas sector and promoting intelligent integration of all sectors. 5. Empowering consumers and aiding EU countries in counteracting energy poverty. 6. Promoting EU standards and energy technologies globally. 7. Using the entire potential of the European offshore wind power.

Source: Authors' own research.

Having analysed the above objectives and goals, as well as the share of the use of conventional resources and renewables, we formulated the following hypotheses:

Hypothesis 1 (H1). *There is a noticeable tendency towards the sustainable development of national energy systems in the EU countries, based on two pillars: a power industry using conventional fossil fuels and one relying on green renewable energy sources.*

Hypothesis 2 (H2). *There is a group of member states which continues to produce energy predominately from conventional fossil sources and a group of countries which exclusively supports the growth of renewables.*

2. Literature Review

Table 3 presents a detailed review of the literature discussing various aspects of energy sourcing and the potential for its use in various areas of the global economy. The literature we analysed pertained to the period from 2006 to 2021 and discussed the use of energy, both from conventional sources (i.e., fossil fuels) and renewable energy, which was generated from new green renewable energy sources that were neutral for people and the environment.

Relatively few publications are dedicated exclusively to sourcing and using energy from conventional fossil fuels. The study [10] analyses global perspectives and forecasts for hard coal production used in the power industry by means of a logistic forecasting model. The article [11] examines the economic and social aspects of the Polish coal mining industry restructuring in the context of requirements arising from Poland's membership in the EU. Its analysis of the hard coal sales forecast (suitable for use in future energy studies) employs an econometric model of time series developed by the authors. The study [12] forecasts the hard coal consumption for Poland's energy demands. The forecasts are based on an ensemble class model developed by the authors involving a combination of several component models, including adaptive boosting, simulated annealing, and the relevance vector machine (RVM). The main question addressed by the authors is whether Poland is able to fulfil its carbon obligations by 2030. Next, the article [13] analyses the consumption of energy from fossil fuels and the impact of sourcing methods on the natural environment in EU countries.

The second group of publications analysed, focused on discussing mostly or exclusively the production and consumption of energy from renewable sources (the so-called "green energy"). The study [14] addresses the question of whether renewable energy could become the driving force behind a sustainable multifaceted economic development of EU countries. Its analyses employ multivariate comparative methods, in particular the panel vector error correction model (PVEC). The article [15] ranks 11 countries from the so-called EU eastern bloc, according to their renewable energy development levels. To this end, the authors designed a development index for ranking purposes, called the index of renewable energy development (IRED). It also [16] analyses the possible development scenarios and evaluates the function of the EU's common integrated energy system in the context of its sustainable energy development and energy transformation, as well as in terms of its transition to renewable energy. This is of special importance in the event of renewable energy shortages in individual member states (as a consequence of the difference in the green energy development potential and the obvious climatic differences across the EU countries) and the resulting necessity to transfer energy over the integrated power system to other member states across borders. The authors analysed scenarios and applied the correlation analysis using Finland and Italy as examples. Similar issues are discussed in [17], which analyses the possible scenarios for Germany's energy system transformation and decarbonization. The study makes use of a technique for generating simulation scenarios (scenario generation), by applying the GENeSYS-MOD energy modelling system. The publication [18] presents an analysis of the energy efficiency in EU countries in terms of sourcing energy from waste recoveries, i.e., the functioning of the circular economy. Our research method was based on a data envelopment analysis (DEA). Many extant studies focused mainly on broadly defined analyses, for example, of the similarities in the development of potential of energy from renewables across countries (mainly of the EU), examining the similarities between those countries in terms of production, consumption, and the use of renewable energy in various sectors of the national economy. This appears highly significant in the context of energy transformation which is under way in many countries globally and the increasing share of renewables in such countries' energy mix. The research employs simple descriptive analysis methods, straightforward data analysis based on tabular and graphic presentations, dynamics indexes, as well as more advanced statistical methods, such as the comparative cluster analysis, various ranking methods, or simulations designed for generating future development scenarios. We may categorise studies [19–34] as belonging to this group. Several other publications discuss slightly different problems concerning green renewable energy. Study [35] forecasts, among other things, the structure of renewable energy production from various sources and biofuels in Poland, with artificial neural networks being applied in the forecast. As part of study [36], surveys were performed, and opinions were collected from Polish and German citizens, relating to the efficiency and effectiveness of the green energy development management in their countries in terms of the EU's implementation of directives related to the current energy transformation and departure from fossil fuels. A similar subject is discussed in [37], in which surveys were carried out to evaluate the development of solar (photovoltaic) energy in Poland in the ongoing process of energy sources decarbonization. In [38], an evaluation is carried out on the potential of hybrid wind/solar power and a forecast is made about its development in the context of an industry decarbonization strategy worldwide. The forecast employs econometric modelling based on the autoregressive distributed Lag (ARDL) model. In [39], analyses are made for the possible development directions for hydrogen as an eco-friendly fuel (where "eco" stands both for the economy and the environment), which may be successfully used as a source of energy, in transport, for instance.

The third group of publications includes studies discussing the development of energy from fossil fuels and renewable sources. Such publications focus primarily on the comparisons between energy potentials of the countries which rely on conventional fossil fuels and modern renewables. Diverse development perspectives have been analysed for energy systems of the member states, based on two pillars of energy stability. Opportunities, obstacles, and threats to modern energy strategies adopted in various countries worldwide have been discussed. A study [40] is devoted to the forecasts regarding energy demand in Turkey, with the sources analysed in the work using the ARIMA method and it includes various traditional fossil fuels as well as renewables. Another study [41] investigates the main challenges (security of energy supply must be underpinned in the long term, efficient actions must be taken to prevent climate change and investment in replacement, new generation plant and grid installations must be made) and barriers (Emission Trading Scheme (ETS), status of CO_2 capture and storage (CCS)) for EU countries in the implementation of the modern energy mix, based on fossil fuels and renewable sources in the process of supplying energy. Possible scenarios for diverse energy development in EU countries, by 2045, are also analysed and assessed. In [42] the authors offer a critical analysis of the directional changes in the Polish power industry, planned by the government from the perspective of the energy package being implemented in the EU. A study [43] included an analysis of the possible scenarios for the transition to a zero-emissions energy system in seven countries in the Nordic-Baltic region. It creates development scenarios with the use of the Balmorel energy system model for the simulation of the positioning of the energy market in consecutive decades, namely 2020, 2030, 2040, and 2050. Another study [44] contains a compelling, comprehensive historical review of the methods of energy generation, an analysis of global demand, and the use of energy from various (non-renewable and renewable) sources worldwide. It also presents future energy demand forecasts (until 2040) by means of dynamics indexes. Several studies analyse scenarios and possible pathways for the planned energy transformation, as well as problems with the decarbonization of the power industry and the transition to green renewable energy, in search of the optimum energy mix. These subjects are discussed in publications [45–47]. A study [48] contains a comparative analysis of the effectiveness of the energy systems based on varied (fossil and renewable) energy sources. The study compares the efficiency of energy systems in the "new" and "old" EU, using the DEA method. Finally, several other studies [49–53] pertain to highly significant and current problems concerning the detailed comparative analysis of the development levels of energy systems in individual countries and their ranking. Such studies employ various statistical analysis methods, including the taxonomic, cluster analysis (in particular the Hellwig method and the k-means method), as well as various ranking methods (TOPSIS, MULTIMOORA, and the green economy index (GEI)).

Table 3. A review of the literature on energy production and the global energy transformation.

Region, Country (Temporal Scope of Data)	Energy Sources		Research Methods Applied	References
	Fossil Fuel Energy	Renewable (Green) Energy		
Turkey (1950–2004)	[x]	[x]	ARIMA, SARIMA forecasting methods	[40]
27 EU countries (2000–2006) (Strategic forecasts until 2045)	[x]	[x]	Scenario analysis Basic statistical descriptive (Tabular and graph analysis)	[41]
World (1950–2008)	[x]		Forecasting methods (logistic model)	[10]
28 EU countries (2003–2014)		[x]	Multivariate econometric analysis (Panel vector error correction model)	[14]
Poland (1995–2014)	[x]		Forecasting methods (econometric model)	[11]
11 countries from the EU's eastern bloc (2005–2015)		[x]	Ranking methods Index of Renewable energy development (IRED)	[15]
Finland, Italy (2013)		[x]	Scenario analysis Correlation analysis	[16]
Germany (scenario simulations until 2050)		[x]	Scenario generation (GENeSYS-MOD energy modelling system)	[17]
Poland (2010–2018)	[x]	[x]	Basic statistical descriptive (table and graph analysis)	[42]
EU countries (2008, 2010, 2012, 2014, 2016)		[x]	Data envelopment analysis (DEA)	[18]

Table 3. *Cont.*

Region, Country (Temporal Scope of Data)	Energy Sources		Research Methods Applied	References
	Fossil Fuel Energy	Renewable (Green) Energy		
Nordic-Baltic region (7 countries) (2016, 2017) (scenario simulations for: 2020, 2030, 2040, 2050)	[x]		Scenario generation Balmorel energy system model for energy market simulations	[43]
European Union EU 28 (2016)	[x]		Kruskal–Wallis statistical independence test	[13]
EU countries (2016–2017)		[x]	Scenario simulation Synchronous grids' dynamic Simulink model	[19]
World (1990–2017) (forecasts until 2040)	[x]		Basic statistical descriptive (table and graph analysis) Indexes of dynamics	[44]
Poland (2015–2050)	[x]		Scenario generation MOEM (model of optimal energy mix) FCM (fuzzy cognitive maps)	[45]
Poland (1990–2018)		[x]	Forecasting methods (ANN artificial neural networks)	[35]
EU countries (2017)		[x]	Cluster analysis (k-means method, Ward method)	[20]
Germany EU countries (scenario simulations until 2050)	[x]		Scenario generation (dynELMOD—dynamic electricity model)	[46]
Poland (1965–2018)	[x]		Ensemble time series prediction models (combined adaptive boosting, simulated annealing and relevance vector machine (RVM))	[12]
28 EU countries (2007–2017)		[x]	Panel-data econometric model Cluster analysis (k-means method)	[21]
Czech Republic (with regard to the European Union) (1995–2017)		[x]	Basic analysis of statistical data (visual presentation of data)	[22]
EU countries (2008–2018)		[x]	Ranking methods: TOPSIS method Principal components analysis (PCA)	[23]
Commonwealth of Independent States (12 countries) (2015–2019)		[x]	Index of dynamics (average change index)	[24]
Western EU (6 countries) (2011, 2018, 2020 targets)		[x]	Basic statistical analysis (tabular analysis, charts)	[25]
28 EU countries (2017–2019)	[x]		Ranking methods (Hellwig's measure of the development)	[49]
Visegrad Group (4 countries, compared to 28 EU countries) (1990–2018)	[x]		Cluster analysis (k-means method) Indexes of dynamics	[50]
28 EU countries (2000–2018)	[x]		Cluster analysis (k-means method) Visualization tools (maps, charts)	[51]
28 EU countries (2004–2019)		[x]	Cluster analysis (Hellwig's taxonomic measure of development) Panel econometric model	[26]
Poland, Germany (2018–2020)		[x]	Survey research	[36]
EU countries (especially Poland and Germany) (2011–2021)		[x]	Basis analysis of statistical data (visual presentation of data)	[27]

Table 3. *Cont.*

Region, Country (Temporal Scope of Data)	Energy Sources		Research Methods Applied	References
	Fossil Fuel Energy	Renewable (Green) Energy		
28 EU countries (in comparison to the Visegrad Group) (2009–2019)		[x]	Cluster analysis (Ward's method)	[28]
28 EU countries (2010, 2018)	[x]		Ranking methods Cluster analysis (GEI—Green Economy Index)	[52]
World (1990–2020)		[x]	Econometric modelling Autoregressive distributed lag (ARDL) model	[38]
27 EU countries (2010–2019)		[x]	Indexes of dynamics (simple individual rankings) Correlation coefficients	[29]
Poland (2011–2020) (forecast estimates for 2021–2025)		[x]	Survey research Basic statistical analysis (tabular analysis, charts)	[37]
28 EU countries (2005–2019)		[x]	Cluster analysis (k-means)	[30]
28 EU countries (2010–2019)		[x]	Ranking analysis (TOPSIS method) Cluster analysis (Czekanowski's method)	[31]
(CEE) Central and Eastern EU countries (10 countries) (2008, 2018)		[x]	Cluster analysis (Ward's method)	[32]
Spain (2015–2019)	[x]		Basic statistical analysis (tabular analysis, charts)	[47]
World (until 2020)		[x]	Scenario analysis Basic statistical descriptive (table and graph analysis)	[39]
28 EU countries (2010–2018)	[x]		DEA (data envelopment analysis)	[48]
28 EU countries (2015, 2019)	[x]		Ranking methods Multicriteria decision making (MULTIMOORA method)	[53]
'New' EU member states (10 countries) (2010, 2015, 2019)		[x]	Cluster analysis (Ward method)	[33]
EU countries (2019)		[x]	Cluster analysis (Ward method) Analysis of variance (ANOVA)	[34]

Source: Authors' own research.

3. Materials and Methods

Well-known and commonly applied linear ordering methods for evaluating multi-feature objects were used in order to compile a ranking of the EU countries with regard to the consumption of energy from conventional fossil-based sources and novel methods of generating the so-called green (environment- and climate-friendly) energy. The analyses relied on the TOPSIS method (technique for order preference by similarity to ideal solution) [54], which implemented the generalized distance measure (GDM) [55,56].

The method assumes the known input diagnostic variable matrix $X_{ij}, i = 1, \ldots, m$; $j = 1, \ldots, n$, where n—the number of the diagnostic variables characterising the investigated objects, m—the number of the ranked (ordered) objects (EU countries) and a set weight vector for the diagnostic variables $w_j \in (0, n); \sum_{j=1}^{n} w_j = n$. Our calculations applied identical weights to each diagnostic variable $w_j = 1$.

The algorithm ranking the EU member states by the type of the energy sources used in generating power includes the following steps:

1. It is expected that all diagnostic variables X_j will be treated as stimulants or destimulants. Features characterised as nominants will be converted to the corresponding stimulant values by the following transformation:

$$X_{ij} = \frac{min\left\{nom_j;\ X_{ij}^N\right\}}{max\left\{nom_j; X_{ij}^N\right\}}, \quad (1)$$

where: X_{ij}^N—the value of the j-th nominant observed for the j-th object, nom_j—the nominal value of the j-th variable.

2. A normalised data matrix is created by means of the standardisation procedure according to the formula:

$$Z_{ij} = \frac{X_{ij} - \overline{X_j}}{S_j}, \quad (2)$$

where: $\overline{X_j}$—the mean value of the j-th primary variable, whereas S_j—the standard deviation of the j-th variable.

3. Coordinates for the pattern vector a^+ (ideal solution) for the optimum values of the diagnostic variables and the anti-pattern vector a^- (anti-ideal solution) for the worst values of the diagnostic variables are determined according to the formulas:

$$a^+ = \left(a_1^+, a_2^+, \ldots, a_n^+\right) := \left\{ \left(\max_{i=1,\ldots,m} Z_{ij} \middle| j \in J_S \right), \left(\min_{i=1,\ldots,m} Z_{ij} \middle| j \in J_D \right) \right\}, \quad (3)$$

$$a^- = \left(a_1^-, a_2^-, \ldots, a_n^-\right) := \left\{ \left(\min_{i=1,\ldots,m} Z_{ij} \middle| j \in J_S \right), \left(\max_{i=1,\ldots,m} Z_{ij} \middle| j \in J_D \right) \right\}, \quad (4)$$

where: J_S—set of stimulants, while J_D—set of destimulants.

4. Calculation of the distance and the i-th object from the pattern GDM_i^+ and the anti-pattern GDM_i^-. The calculations used the GDM (generalized distance measure):

$$GDM_i^+ = \frac{1}{2} - \frac{\sum_{j=1}^n w_j\left(Z_{ij} - a_j^+\right)\left(a_j^+ - Z_{ij}\right) + \sum_{j=1}^n \sum_{l=1,l\neq i,l\neq i_+}^m w_j\left(Z_{ij} - Z_{lj}\right)\left(a_j^+ - Z_{lj}\right)}{2\left[\sum_{j=1}^n \sum_{l=1}^m w_j\left(Z_{ij} - Z_{lj}\right)^2 \cdot \sum_{j=1}^n \sum_{l=1}^m w_j\left(a_j^+ - Z_{lj}\right)^2\right]^{\frac{1}{2}}}, \quad (5)$$

$$GDM_i^- = \frac{1}{2} - \frac{\sum_{j=1}^n w_j\left(Z_{ij} - a_j^-\right)\left(a_j^- - Z_{ij}\right) + \sum_{j=1}^n \sum_{l=1,l\neq i,l\neq i_-}^m w_j\left(Z_{ij} - Z_{lj}\right)\left(a_j^- - Z_{lj}\right)}{2\left[\sum_{j=1}^n \sum_{l=1}^m w_j\left(Z_{ij} - Z_{lj}\right)^2 \cdot \sum_{j=1}^n \sum_{l=1}^m w_j\left(a_j^- - Z_{lj}\right)^2\right]^{\frac{1}{2}}}, \quad (6)$$

where: i_+—pattern object index (number), whereas i_-—anti-pattern object index (number).

5. An aggregate measure (ranking index) corresponding to the degree of similarity of the investigated objects to the ideal solution, is determined according to the formula:

$$TOPSIS\ (GDM) R_i = \frac{GDM_i^-}{GDM_i^- + GDM_i^+}, \quad (7)$$

For $i = 1, \ldots, m$; where: $0 \leq R_i \leq 1$.

6. The objects are placed in a decreasing order depending on the value of measure R_i and the final ranking is generated for the objects (European Union countries). The greater the values of the calculated synthetic index for the country, the higher the country's position in the ranking.

In addition, the analysis made use of an agglomerative clustering—Ward's method—which employs the analysis of variance approach in its procedures [57]. It seeks to minimize the sums of the squared deviations in any pair of clusters which may be formed at any test stag and is one of the most effective clustering methods. The sequence of steps in Ward's method resembles other agglomerative approaches. Significant differences occur in the parameters used in the formula. The sequence is as follows: first, a matrix of taxonomic distances of the dimensions n × n is created, containing the distance between each pair of objects. The matrix is symmetrical in relation to the core diagonal, which is composed of zeros only. Next, the procedure involves searching for pairs of objects (and then clusters) for which the mutual distance is the shortest. The objects are labelled "p" and "q", with p < q. Then, "p" and "q" are combined into a single cluster, which occupies the position labelled with number "p". At the same time, object "q" (cluster) is removed, and the numbers of clusters higher than the "q" object are incremented by one. In this way, the dimension of the matrix is decreased by 1. Next, the distance of the new cluster to each remaining one is calculated according to the formula:

$$D_{pr} = a_1 \cdot d_{pr} + a_2 \cdot d_{qr} + b \cdot d_{pq}, \tag{8}$$

where: D_{pr}—distance from the new cluster to cluster "r", d_{pr}—distance of original cluster "p" to cluster "r", d_{qr}—distance to original cluster "q" from cluster "r", d_{pq}—relative distance between the original clusters "p" and "q", a_1, a_2, b—parameters calculated in Ward's method by formulas:

$$a_1 = \frac{n_p + n_r}{n_p + n_q + n_r}, \quad a_2 = \frac{n_q + n_r}{n_p + n_q + n_r}, \quad b = \frac{-n_r}{n_p + n_q + n_r}. \tag{9}$$

n_P, n_q, n_r—means the quantity of single objects in each group.

The group means method was used to describe the newly formed clusters. An analysis of the group means was performed for the resulting clusters, with the aim of obtaining indicators (diagnostic features) dominant in a given group. For the numerical data matrix, the overall arithmetic means of indicators (without grouping) were calculated and labelled by $\overline{\mathrm{W}}_{\mathrm{i}}$. Next, the group arithmetic means of the indicators in resulting clusters were calculated and labelled as $\overline{\mathrm{w}}_{\mathrm{i}}$. The structural index of each cluster is the quotient $\frac{\overline{\mathrm{w}}_{\mathrm{i}}}{\overline{\mathrm{W}}_{\mathrm{i}}}$. High values of the structural index of the means offer information about the dominance of a specific feature in the resulting group. If the mean level of a phenomenon in the group is identical to its mean level across the entire population of objects, then the quotient of means equals 1 (or 100%). Values in excess of 1 (>100%) demonstrate that the mean level of the factor in the group is significantly above its overall mean, while values lower than 1 (<100%) indicate that the mean level of the factor is lower in the investigated group, comparatively to the entire analysed population.

4. Results

An analysis was performed based on the selected indicators, allowing us to create two rankings pertaining to the use of fossil fuels and renewables.

4.1. Data Characteristics

The taxonomic analyses relied on information from the databases kept by Eurostat—the European Statistical Office. The statistical data processed in the study were related to the generation, use, and consumption of energy from various sources (traditional fossil fuels and green renewables), resource levels, as well as the consumption of various types of fuel for power generation purposes in the process of electricity production. The analyses were performed for 2019 (latest available Eurostat data at the time of drafting this article).

Original statistical data retrieved mainly from the Eurostat database (https://ec.europa.eu/eurostat/web/energy/data/database (accessed on 9 July 2022)) were used in the statistical analyses.

Certain data in the statistical-taxonomic analyses were pre-processed on the basis of the original data values and expressed as intensity indicators for the primary diagnostic variables, representing their values converted per 1 million inhabitants of a given country.

A total of 15 indicators characterising the use of fossil fuels and renewables in 28 EU countries, in 2019, were selected for the purpose of this study. The indicators selected for further analysis were labelled (X_1 to X_{15}), with the following meaning and interpretation:

X_1—Stock levels for oil products (fuel oil) [thousand tonnes]/1 [million inhabitants] [58,59];

X_2—Share of fossil fuels in gross available energy [%] [60];

X_3—Final consumption—energy use (hard coal) [thousand tonnes]/1 [million inhabitants] [59,61];

X_4—Gross electricity production (fossil fuels) [thousand tonnes of oil equivalent]/1 [million inhabitants] [59,62];

X_5—Stock levels for natural gas [million cubic meters]/1 [million inhabitants] [59,63];

X_6—Share of fuels in final energy consumption—energy use (natural gas) [%] [64];

X_7—Gross electricity production (natural gas) [thousand tonnes of oil equivalent]/1 [million inhabitants] [59,62];

X_8—Energy available for final consumption (oil and petroleum products excluding biofuels) [thousand tonnes of oil equivalent]/1 [million inhabitants] [59,65];

X_9—Solar thermal collector surface [square meters]/1 [million inhabitants] [59,66];

X_{10}—Share of fuels in final energy consumption—energy use (renewables and biofuels) [%] [64];

X_{11}—Liquid biofuels production capacities (pure biodiesels) [thousand tonnes per year]/1 [million inhabitants] [59,67];

X_{12}—Electricity production capacities for renewables and wastes (hydro) [megawatt]/1 [million inhabitants] [59,68];

X_{13}—Total energy supply (geothermal) [thousand tonnes of oil equivalent]/1 [million inhabitants] [59,69];

X_{14}—Total energy supply (wind) [thousand tonnes of oil equivalent]/1 [million inhabitants] [59,69];

X_{15}—Total energy supply (solar—photovoltaic) [thousand tonnes of oil equivalent]/1 [million inhabitants] [59,69].

Table 4 lists the indicators analysed in the study and their basic descriptive statistics.

Table 4. Descriptive statistics of selected variables.

Variable	Mean	Min	Max	σ	V_z	S
Variables used in the country ranking for the development of a fossil fuel-based energy industry.						
X_1	35.5	0	152.8	39.4	110.9	1.3
X_2	72.3	31.8	96.7	14.7	20.3	−0.8
X_3	45.6	0	400.5	75.1	164.7	4.2
X_4	62.5	0	301.4	85.9	137.5	1.7
X_5	184.1	0	959.3	260.4	141.5	1.7
X_6	16.4	0	37.3	10.2	62.3	0.2
X_7	100.5	0	350.7	96.5	96.0	1.2
X_8	1025.1	475.8	3825.2	611.4	59.6	3.8
Variables used in the country ranking for the development of a green renewable energy industry.						
X_9	146.6	0	1237.7	253.5	172.9	3.4
X_{10}	12.5	4.3	27.4	6.4	50.8	0.9
X_{11}	39.2	0	122.9	35.9	91.4	0.7
X_{12}	449.1	0	2167.3	542.3	120.8	1.9
X_{13}	6.4	0	90.2	17.2	267.7	4.6
X_{14}	61.6	0	239.2	59.5	96.7	1.4
X_{15}	15.8	0.1	48.0	12.5	79.2	0.8

σ—standard deviation, V_z—coefficient of variation, S—skewness. Source: Authors' own research.

The table splits the data into two categories: the features which were used to rank the countries by the use of fossil fuel energy sources (X_1–X_8), and the features which were applied to rank the countries by the use of renewables (X_9–X_{15}). Meanwhile, the full set of indicators (X_1–X_{15}) was used for the classification by means of Ward's method.

All indicators selected for the purpose of the present study are highly variable, as demonstrated by the standard deviation and the coefficient of variation. The highest variability across countries was reported for three indicators: X_{13}—Total energy supply (geothermal), X_9—Solar thermal collector surface, and X_3—Final consumption—energy use (hard coal).

The coefficient of variation for X_{13} was 267.7%. As many as eight countries (Estonia, Ireland, Latvia, Lithuania, Luxembourg, Malta, Finland, and Sweden) lack any supply of geothermal energy. In contrast, in Italy, the index reaches the highest value of 90.2 [thousand tonnes of oil equivalent] per 1 [million people].

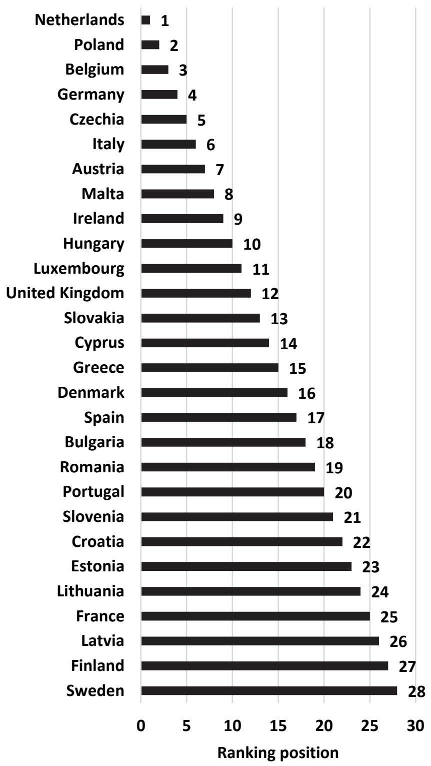
The use of solar collectors 7 (variable X_9) also reveals major differences across the EU, with a coefficient of variation of 172.9%. In Estonia, Lithuania, and Slovakia, the index has a value of 0. In contrast, it is the highest for Cyprus—specifically 1237.7 [square meters] per 1 [million inhabitants].

In the fossil fuel group, index X_3 is characterised by the highest variability, as its coefficient of variation equals 164.7%. The lowest value (0) of the index is reported for Malta, and the highest is in Poland, namely 400.5 [thousand tonnes] per 1 [million inhabitants].

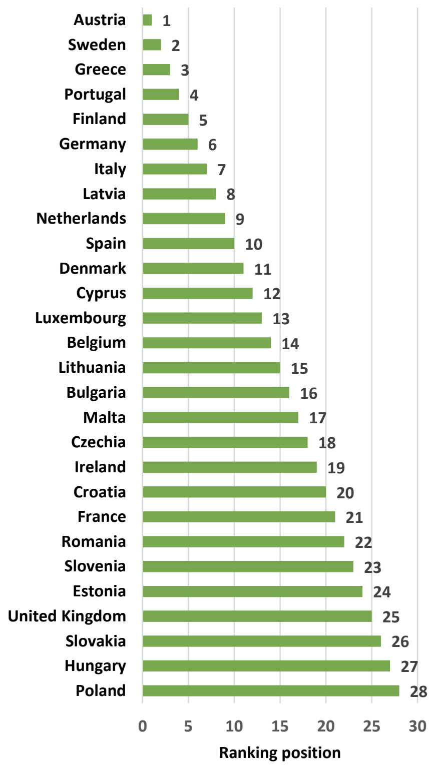
All indicators except for one reveal a right-hand skewness, i.e., for most countries the values of the indicators are below the mean level for the specific feature. The only index which stands out in this respect is: X_2—Share of fossil fuels in gross available energy. It displays a left-hand skewness, which means that in most of the countries analysed in this study, the share of fossil fuels in gross available energy is higher than the calculated mean value.

4.2. EU Countries' Rankings Depending on the Energy Sources Used

Two rankings were compiled (Figure 4) on the basis of the variables investigated in this study: one with regard to the use of fossil fuels and another with regard to the use of renewables. The results reveal that the consumption of fossil fuels and renewables is strongly varied across the analysed member states. Poland proves to be the most controversial case, with the second position in the fossil fuel ranking and the last position in the renewable sources ranking.



(a)



(b)

Figure 4. EU countries' ranking in terms of: (**a**) fossil fuels; (**b**) renewables. Source: authors' own research.

The best situation is observed for countries with an optimal mixed approach to the use of conventional fossil fuels and green renewables.

The largest share in the consumption of fossil fuels is observed for the Netherlands (1st position), Poland (2nd position), and Belgium (3rd position). In contrast, the smallest share of fossil fuels is reported for Lithuania (26th position), Finland (27th position), and Sweden (28th position). As for the renewable energy sources, Austria leads the ranking (1st position), followed by Sweden (2nd position), and Greece (3rd position). At the bottom of the ranking are Slovakia (26th position), Hungary (27th position), and Poland (28th position).

4.3. Analysis of the Similarities in Obtaining Energy from Various Sources in EU Countries with the Use of Cluster Analysis Methods

Based on features selected for the purpose of this study, the countries were grouped according to their use of both fossil and renewable fuels in order to facilitate the ranking analysis. The study made use of the taxonomic grouping method (Ward's method), which enabled a more detailed analysis of the country groups identified, thus characterising them in terms of the utilisation of various energy sources. Based on the scree plot (Figure 5a), a decision was made to split the Ward's diagram at the linkage distance of 8.4, as at that point on the scree plot, a marked surge in the linkage distance is clearly visible. There is also a significant value on level 4 of the linkage distance, although a split at that length would generate too many clusters (multiple single-element clusters), and as such would prove far from helpful in drawing conclusions. For this reason, a split into five clusters was preferred.

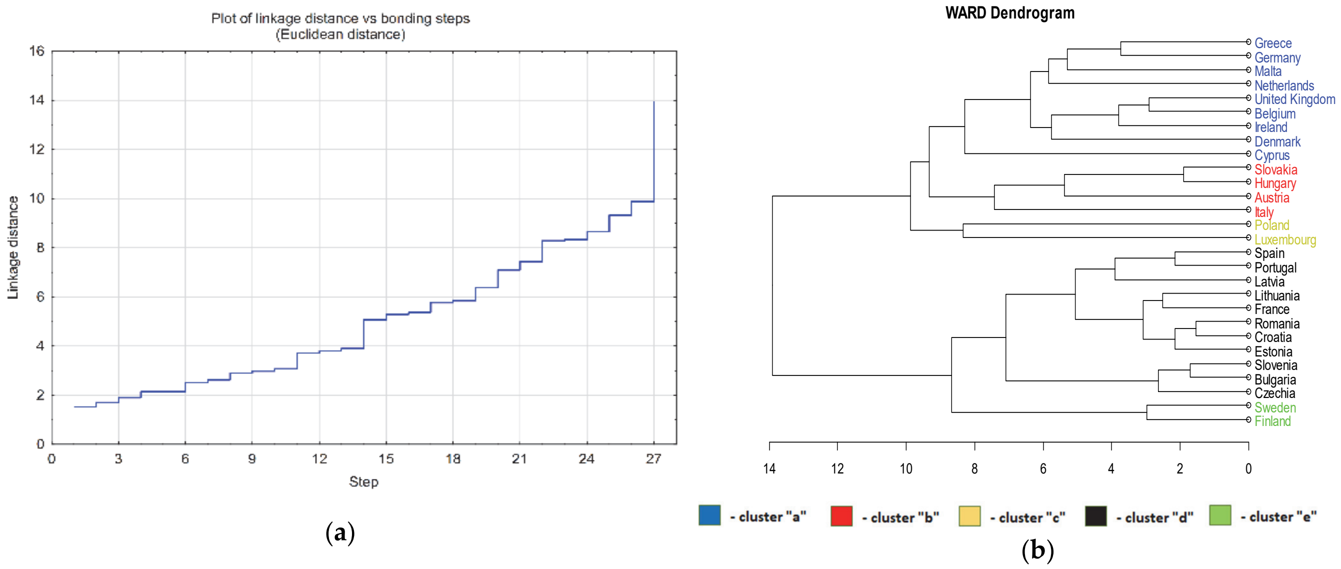


Figure 5. Results of the cluster analysis using Ward's method: (**a**) scree plot; (**b**) dendrogram—Ward's method (Euclidean distance). Source: Authors' own research.

The first cluster, labelled "a", included nine countries: Belgium, United Kingdom, Ireland, Denmark, Germany, Greece, Malta, the Netherlands, and Cyprus. These countries had relatively solid positions in the rankings due to the use of renewables but ranked highly also in terms of their use of fossil fuels. A conclusion which can be drawn from the analysis of the quotient of the group mean indicators (Figure 6) is that the cluster is characterized by high values for X_1—Stock levels for oil products (fuel oil) and X_7—Gross electricity production (natural gas), as well as elevated use of thermal energy, with the more-than-average values of index X_9—Solar thermal collector surface. The solar energy indicator X_{15} also reaches above-average values (the highest of all clusters). The same holds true for the wind energy index, although not to such a considerable extent as in the countries from cluster "e".

Labelled "b", the second cluster groups together four countries, namely Austria, Hungary, Slovakia, and Italy. Austria and Italy rank high in terms of the exploitation of both fossil and renewable energy sources, whereas Hungary and Slovakia also have high positions in fossil fuels, yet also extremely low positions with regard to the use of renewables. An analysis of the quotient of the group mean indicators indicates that the use of geothermal energy reaches radically elevated levels (above-average values of indicator X_{13}). Remarkably high values are also reached by indicators X_5 and X_6, which correspond to energy production from natural gas. What is more, the countries in the cluster also show a considerable consumption of solar (photovoltaic) and water power (hydropower), as demonstrated by the above-average mean quotients for the diagnostic variables X_9, X_{15}, and X_{12}.

The third cluster, named "c", included two countries: Luxembourg and Poland. This pair appears quite peculiar, although this study is concerned with the use of energy sources rather than economic development. Consequently, the fact that the two countries were placed in the same cluster should be seen as perfectly natural. Indicator X_3, Final consumption—energy use (hard coal), has definitely the highest quotient of means in the group. The feature corresponds to the consumption of energy from fossil fuels, particularly hard coal. High values of the quotient of means were also found for indicators such as: X_4—Gross electricity production (fossil fuels) and X_8—Energy available for final consumption (oil and petroleum products excluding biofuels).

The fourth cluster, coded "d", contains the largest number of objects (11 countries), namely Bulgaria, Slovenia, the Czech Republic, Croatia, Romania, Estonia, France, Lithuania, Latvia, Portugal, and Spain. These are mostly countries which ranked last in terms of the use of renewables or non-renewables. The Czech Republic is the only member state with a high (5th) position in the fossil fuel ranking in this group, while Portugal and Latvia perform quite well in terms of the exploitation of renewable energy sources. Although they are countries with an average consumption of both types of sources, they generate a considerable portion of energy from fossil fuels.

The last cluster, labelled "e", consists of two countries: Sweden and Finland. They have high (2nd and 5th) positions in the renewables ranking. In addition, they are at the bottom of the list of countries which use fossil fuels (27th and 28th position). However, the group mean quotient analysis reveals that these countries are characterised by an above-average level of indicators corresponding to the use of renewables. Specifically, variables with a remarkably high share include X_{12}—Electricity production capacities for renewables and wastes (hydro), X_{14}—Total energy supply (wind) and X_{10}—Share of fuels in final energy consumption—energy use (renewables and biofuels), as well as X_{11}—Liquid biofuels production capacities (pure biodiesels).

Figure 7 presents countries plotted at coordinates corresponding to the computed ranking positions and divided into four groups. The EU countries may be categorised as: (1) countries with a very high position in both energy sources rankings, (2) those with the lowest position in both rankings, (3) and (4) those with only one well-developed area of power industry, i.e., relying either on fossil fuels or renewables.

From Figure 7, we may conclude that the countries which occupy the top positions in both rankings include the Netherlands, Germany, Austria, and Italy. They are leaders in both areas, with high fossil fuels' and renewables' consumption levels. Countries at the bottom of both rankings include France, Estonia, Slovenia, and Croatia.

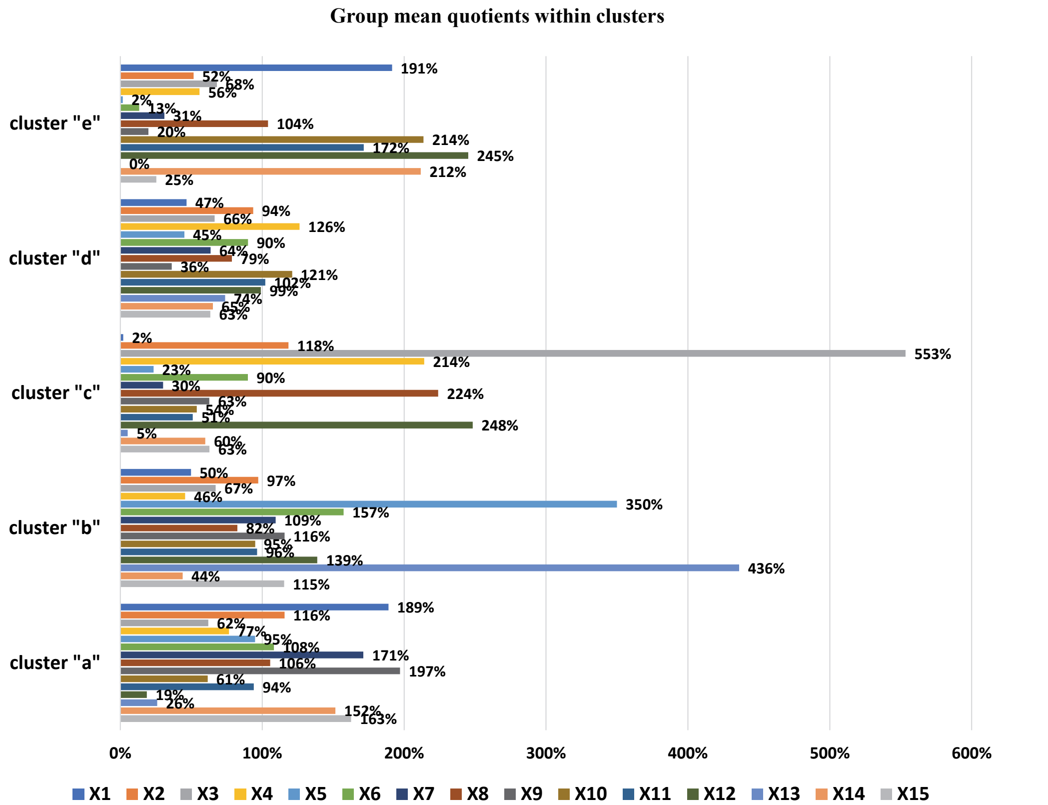


Figure 6. Percentage share of the group means comparatively to the overall mean for the selected diagnostic variables in the clusters obtained by Ward's method. Source: Authors' own research.

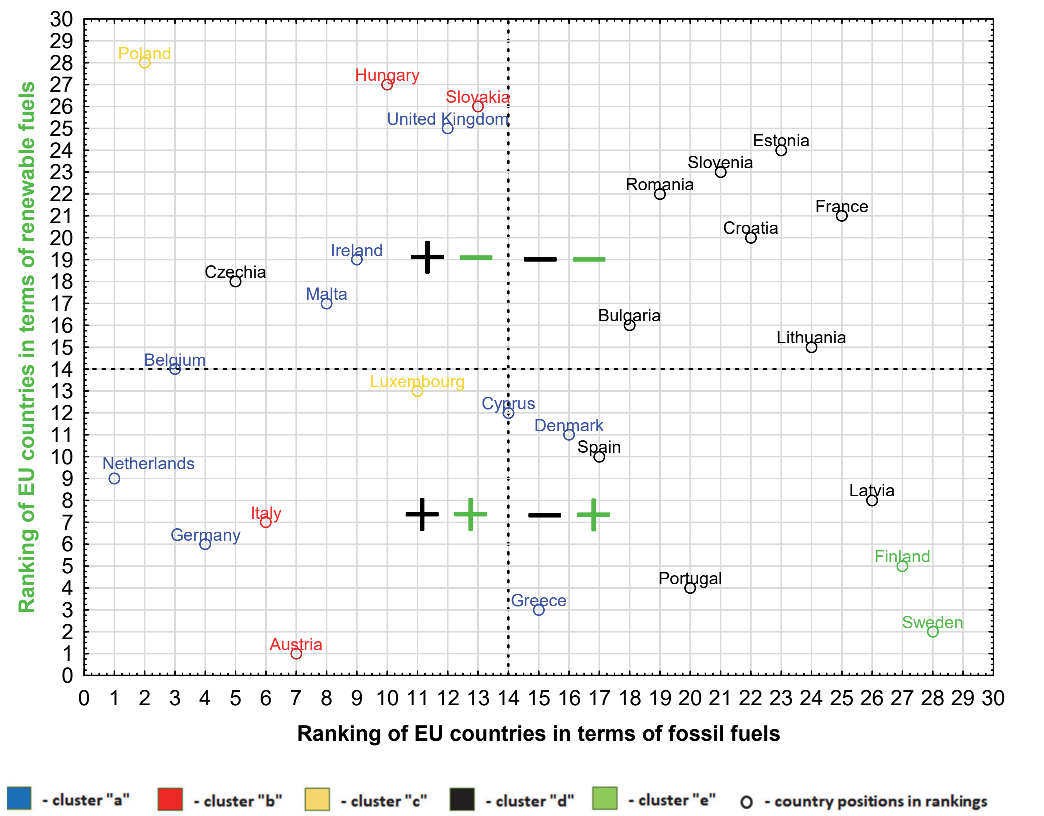


Figure 7. A visualisation of the two rankings and four groups of the EU countries. Source: Authors' own research.

5. Discussion

With global energy demand on a constant increase, ensuring current production levels and creating favourable conditions for future economic growth means that energy must be easily available and inexpensive, and the supply system must be resistant to various disruptions. Power outages may lead to substantial financial losses and wreak havoc in its functioning. Equally important are the energy availability and the ability to purchase it at reasonable and acceptable prices. Energy security, understood as guaranteed energy supply, is usually defined in terms of the energy system's resistance to exceptional and unpredictable events which may threaten the physical integrity of energy flow or cause an uncontrollable price surge, regardless of its economic rationale [70]. Energy security ensures that consumers' current and future demands for fuels and energy are met in a technically and economically justified way, with a minimum negative effect of the energy sector, on the environment and living conditions.

The predicted increase in the demand for energy necessitates its supply from multiple sources. A diversified energy mix guarantees security for the energy system thanks to its elasticity in meeting the requirements of a given country. Most renewable energy sources are intermittent [71], which opens spatial and temporal gaps between their availability and consumption by end users. To tackle this issue, the employment of large-scale energy storage systems may greatly improve the utilisation rate and stability of the use of renewable energy. The pumped hydro energy storage technology, for example, can quickly balance the load and adjust the frequency to meet the requirements of the power system [72], as well as the redox flow batteries being a representative of electrochemical energy storage technique [73].

Energy supply security depends on many factors, amongst which, several key determinants can be highlighted:

- diversity (diversification) of capabilities—sustainable and well-balanced energy production systems including various power generation technologies, together with suitable production capabilities help to make maximum use of advantages offered by a specific technology;
- interchangeability of fuels—diversity in the consumption of fuels may be a crucial factor to enhancing energy security. Conversion of fuels such as coal into gas, gas into liquid fuel, and coal gasification facilitate meeting the demand even if conventional fuel supplies are disrupted;
- political threats—the energy supply system may be exposed to threats and disorganisation due to various, often conflicting political interests of different countries, or due to terrorist attacks

The invasion of Ukraine forced the European countries to look for immediate responses involving the replacement of raw materials which had been imported from the East barely some months before. At present, Europe is amidst the decarbonization process with gas as a transition fuel—ironically, a fuel imported from Russia.

There are many signs that a domestic mining industry and access to coal deposits will remain a diversifying factor relevant for the energy security. From the power industry's standpoint, an ideal solution would be to rely on many diverse sources to enhance security and guarantee a continuous energy supply—a sine qua non of the existence and constant growth of a modern society.

The analysis performed in this article demonstrated that EU countries use conventional and renewable sources to a varying degrees. The choice of the strategy depends on the state's resources, geographical and climate factors, sea access, sunlight, wind intensity, and the presence of fossil fuel deposits.

The research results presented in the article, despite being obtained only for the 15 indicators (determinants of energy use based fossil and renewable sources) selected for the study are comparable with the findings of other publications dealing with renewable energy sources' development in EU countries. However, a full comparison with such findings is not possible due to the use of various sets of diagnostic indicators and different research methods by the authors. It is worthy of note that much of the aforementioned studies dealt with the use of renewable energy only, while a few others dealt with energy use from both energy sources (fossil and renewable). Our study covers both approaches and also indicates which approaches are dominant in a given EU country.

Similar synthetic measures confirming the more favourable situation in terms of renewable sources based (solar, wind, hydro, and bio) electricity production in the rich old EU members, while highlighting problems with the greening of electricity production in the large group of new EU member states were presented in article [26]. The observations contained in the article corroborate our findings, rankings in development of renewable energy development in highly developed old EU countries, including Austria, Sweden, Finland, Portugal, and Germany and also the relatively poorer use of renewable sources based energy in poorer Eastern European countries despite observable changes.

In [20], the authors showed an elaborate variety of sources from which renewable energy is obtained in some EU countries. This is attributable to their geographical locations, financial capabilities, traditions, as well as economic potentials and social awareness. Consequently, there are great opportunities for cooperation and exchange of experience in this area between individual countries, which should result in a more comprehensive and effective use of countries' individual renewable energy sources.

Similarly, in [23] the results of the author's study showed that EU countries are characterized by significant differences in the development of renewable energy sources, in 2018. The unquestionable leaders in this respect are Sweden, Austria, Finland, and Latvia, which is also confirmed by study findings.

A group of member states, including Germany, Italy, Austria, and the Netherlands, have a highly diversified strategy for their power industry, as they take advantage of both conventional and renewable energy sources. Greece, Portugal, Finland, and Sweden currently rely mostly on renewables, while the power industries of Poland, Belgium, the Czech Republic, and Malta, are based largely around fossil fuels. Countries with the lowest level of energy security make limited use of both types of energy sources, and these include Estonia, France, Slovenia, and Croatia.

The European Union has, for long, been applying strategies and actions, aimed at motivating member states to increase their share in obtaining renewable sources based energy. Such strategies and actions by the EU have already brought tangible effects, currently visible even in countries such as Poland that traditionally base their energy industry on fossil sources. The data analysis, presented in Figures 1 and 2 in the introduction section, provides such a conclusion.

However, these measures seem insufficient in the context of the observed climate changes. Therefore, the EU ought to further stimulate more intense country involvement in renewable energy sources development through actions such as:

- financing development investments in wind, solar, hydro, geothermal, and bio-energy,
- applying tax breaks for companies in the renewable energy sector,
- introducing higher restrictions on the required share of renewable energy in the total value of energy obtained,
- increasing country and energy consumers' awareness that renewable energy is an unavoidable and important source of energy.

Taking cognizance of the fact that obtaining renewable energy at similar levels due to factors earlier mentioned and the previously signalled discontinuities in the renewable energy sources supply is impossible in all countries, the European Union should also reinforce support for initiatives in co-financing investments in ecological energy production from fossil sources. Basing a country's energy sector solely on one pillar, such as renewable energy, or on any other source, such as gas, is very risky and adversely affects the country's energy stability as has recently been confirmed by the current war in Ukraine.

6. Conclusions

The analyses were based on quantitative indicators, describing energy derived from both fossil and renewable sources, which is rarely undertaken in previous similar studies, where predominant analytical approaches were solely based on the developments in countries' green energy sector and the use of energy from renewable sources.

Our study used methods of multivariate comparative analysis, such as Ward's cluster analysis method and the ranking method based on the synthetic measure of the TOPSIS development.

The findings of this study corroborate our research hypotheses formulated at the beginning, namely that EU countries display a tendency to foster sustainable development of their energy systems based on two pillars (both energy from conventional fossil fuels, and green renewable energy sources). Such countries include Austria, Germany, Italy, and the Netherlands. On the other hand, there is a group of member states which continue to produce energy predominately from conventional fossil sources (Poland and the Czech Republic), as well as a group of those which exclusively support the growth of their power industry based on renewables, such as Finland and Sweden.

The research was carried out relying on statistical data from 2019. Hence, it is planned that future long-term (2022–2030) studies should be undertaken in order to compare future results with current findings.

Given the present uncertainties in terms of energy supply, emphasis must be put on the diversification of energy sources to ensure the highest possible level of energy security, a guarantor of further socio-economic development.

The conclusions drawn from this study can serve as recommendations for decision makers in developing energy strategies and can help identify countries which require assistance in choosing appropriate development paths in terms of their energy strategy.

The research on the use of hydrogen as a clean energy source seems hopeful in the pursuit for improving EU countries' energy balance. In terms of accelerating the development of renewable energy, the EU hopes to achieve its goal by producing 10 million tons of green hydrogen, while importing another 10 million tons by 2030. The current energy prices in Europe are relatively high globally, and the use of renewable energy will further increase the cost of green hydrogen production in Europe, although large-scale long-distance transportation technology of hydrogen is yet to mature.

In addition, European Commission decision makers have proposed to double the solar PV capacity by 2025 and install 600 GW by 2030. In order to support the solar energy industry in Europe and retain and regain its technological and industrial leading position in the field of solar energy, the European Union has decided to set up the "EU Solar Energy Industry Alliance", hoping that in the process of energy transformation, European enterprises can assail their desired market position.

Author Contributions: Conceptualization, K.C.-L. and T.P.; methodology, K.C.-L. and T.P.; validation, K.C.-L. and T.P.; investigation, K.C.-L. and T.P.; resources, K.C.-L. and T.P.; data curation, K.C.-L. and T.P.; writing—original draft preparation, K.C.-L. and T.P.; writing—review and editing, K.C.-L. and T.P.; visualization, K.C.-L. and T.P.; supervision, K.C.-L. and T.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commission. Available online: https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#documents (accessed on 10 April 2022).
2. EU Monitor. Available online: https://www.eumonitor.eu/9353000/1/j4nvke1fm2yd1u0_j9vvik7m1c3gyxp/vkcwedk9layr/v=s7z/f=/com(2016)860_en.pdf (accessed on 10 April 2022).
3. EUR-LEX. Available online: https://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN (accessed on 10 April 2022).
4. United Nations Climate Change. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 10 April 2022).
5. EUR-LEX. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF (accessed on 10 April 2022).
6. EUR-LEX. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:dbb7eb9c-e575-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF (accessed on 10 April 2022).
7. EUR-LEX. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550&from=PL (accessed on 10 April 2022).
8. EUROSTAT. Available online: https://ec.europa.eu/eurostat/documents/2995521/10335438/8-23012020-AP-EN.pdf/292cf2e5-8870-4525-7ad7-188864ba0c29 (accessed on 10 April 2022).
9. EUROSTAT. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics (accessed on 10 April 2022).
10. Hook, M.; Zittel, W.; Schindler, J.; Aleklett, K. Global coal production outlooks based on a logistic model. *Fuel* **2010**, *89*, 3546–3558. [CrossRef]
11. Manowska, A.; Tobór Osadnik, K.; Wyganowska, M. Economic and social aspects of restructuring Polish coal mining: Focusing on Poland and the EU. *Resour. Policy* **2017**, *52*, 192–200. [CrossRef]
12. Li, Y.; Zhang, H.; Kang, Y. Will Poland fulfil its coal commitment by 2030? An answer based on a novel time series prediction method. *Energy Rep.* **2020**, *6*, 1760–1767. [CrossRef]
13. Martins, F.; Felgueiras, C.; Smitkova, M.; Caetano, N. Analysis of fossil fuel energy consumption and environmental impacts in European Countries. *Energies* **2019**, *12*, 964. [CrossRef]
14. Armeanu, D.S.; Vintila, G.; Gherghina, S.C. Does renewable energy drive sustainable economic growth? Multivariate panel data evidence for EU-28 countries. *Energies* **2017**, *10*, 381. [CrossRef]
15. Momete, D.C. Measuring Renewable Energy Development in the Eastern Bloc of the European Union. *Energies* **2017**, *10*, 2120. [CrossRef]
16. Wang, H.; Di Pietro, G.; Wu, X.; Lahdelma, R.; Verda, V.; Haavisto, I. Renewable and sustainable energy transitions for countries with different climates and renewable energy sources potentials. *Energies* **2018**, *11*, 3528. [CrossRef]
17. Bartholdsen, H.-K.; Eidens, A.; Loffler, K.; Seehaus, F.; Wjda, F.; Burandt, T.; Oei, P.-Y.; Kemfert, C.; von Hirschhausen, C. Pathways for Germany's low-carbon energy transformation towards 2050. *Energies* **2019**, *12*, 2988. [CrossRef]
18. Halkos, G.; Petrou, K.N. Analysing the energy efficiency of EU member states: The potential of energy recovery from waste in the circular economy. *Energies* **2019**, *12*, 3718. [CrossRef]
19. Agathokleous, C.; Ehnberg, J. A quantitative study on the requirement for additional inertia in the European Power System until 2050 and the potential role of wind power. *Energies* **2020**, *13*, 2309. [CrossRef]
20. Brodny, J.; Tutak, M. Analyzing similarities between the European Union Countries in terms of the structure and volume of energy production from renewable energy sources. *Energies* **2020**, *13*, 913. [CrossRef]
21. Simionescu, M.; Strielkowski, W.; Tvaronaviciene, M. Renewable energy in final energy consumption and income in the EU-28 countries. *Energies* **2020**, *13*, 2280. [CrossRef]
22. Sivek, M.; Jirasek, J.; Kavina, P.; Vojnarova, M.; Kurkova, T. Divorce after hundreds of years of marriage: Prospects for coal mining in the Czech Republic with regard to the European Union. *Energy Policy* **2020**, *142*, 111524. [CrossRef]
23. Brodny, J.; Tutak, M.; Bindzar, P. Assessing the level of renewable energy development in the European Union member states. A 10-year perspective. *Energies* **2021**, *14*, 3765. [CrossRef]
24. Chowaniak, M.; Gródek-Szostak, Z.; Kotulewicz-Wisińska, K.; Luc, M.; Suder, M.; Szeląg-Sikora, A. The RES in the Countries of the Commonwealth of Independent States: Potential and Production from 2015 to 2019. *Energies* **2021**, *14*, 1856. [CrossRef]
25. Cucchiella, F.; Condemi, A.; Rotilio, M.; Annibaldi, V. Energy transitions in Western European Countries: Regulation comparative analysis. *Energies* **2021**, *14*, 3940. [CrossRef]
26. Huterski, R.; Huterska, A.; Zdunek-Rosa, E.; Voss, G. Evaluation of the level of electricity generation from renewable energy sources in European Union countries. *Energies* **2021**, *14*, 8150. [CrossRef]
27. Jałowiec, T.; Wojtaszek, H. Analysis of the RES potential in accordance with the energy policy of the European Union. *Energies* **2021**, *14*, 6030. [CrossRef]
28. Kacperska, E.; Łukasiewicz, K.; Pietrzak, P. Use of renewable energy sources in the European Union and the Visegrad Group countries—Results of cluster analysis. *Energies* **2021**, *14*, 5680. [CrossRef]

29. Komarnicka, A.; Murawska, A. Comparison of consumption and renewable sources of energy in European Union Countries—Sectoral indicators, economic conditions and environmental impacts. *Energies* **2021**, *14*, 3714. [CrossRef]
30. Matuszewska-Janica, A.; Żebrowska-Suchodolska, D.; Ala-Karvia, U.; Hozer-Koćmiel, M. Changes in electricity production from renewable energy sources in the European Union countries in 2005–2019. *Energies* **2021**, *14*, 6276. [CrossRef]
31. Musiał, W.; Zioło, M.; Luty, L.; Musiał, K. Energy policy of European Union Member states in the context of renewable energy sources development. *Energies* **2021**, *14*, 2864. [CrossRef]
32. Pakulska, T. Green energy in Central and Eastern European (CEE) countries: New challenges on the path to sustainable development. *Energies* **2021**, *14*, 884. [CrossRef]
33. Wałachowska, A.; Ignasiak-Szulc, A. Comparison of renewable energy sources in 'New' EU Member States in the context of national Energy transformations. *Energies* **2021**, *14*, 7963. [CrossRef]
34. Włodarczyk, B.; Firoiu, D.; Ionescu, G.H.; Ghiocel, F.; Szturo, M.; Markowski, L. Assessing the sustainable development and renewable energy sources relationship in EU countries. *Energies* **2021**, *14*, 2323. [CrossRef]
35. Brodny, J.; Tutak, M.; Saki, S.A. Forecasting the structure of energy production from renewable energy sources and biofuels in Poland. *Energies* **2020**, *13*, 2539. [CrossRef]
36. Jałowiec, T.; Wojtaszek, H.; Miciuła, I. Green energy management through the implementation of RES in the EU. Analysis of the opinions of Poland and Germany. *Energies* **2021**, *14*, 8097. [CrossRef]
37. Lew, G.; Sadowska, B.; Chudy-Laskowska, K.; Zimon, G.; Wójcik-Jurkiewicz, M. Influence of photovoltaic development on decarbonization of power generation—Example of Poland. *Energies* **2021**, *14*, 7819. [CrossRef]
38. Khan, H.R.; Awan, U.; Zaman, K.; Nassani, A.A.; Haffar, M.; Abro, M.M.Q. Assessing hybrid solar-wind potential for industrial decarbonization strategies: Global shift to green development. *Energies* **2021**, *14*, 7620. [CrossRef]
39. Sharma, S.; Agarwal, S.; Jain, A. Significance of Hydrogen as Economic and Environmentally Friendly Fuel. *Energies* **2021**, *14*, 7389. [CrossRef]
40. Ediger, V.S.; Akar, S. ARIMA forecasting of primary energy demand by fuel in Turkey. *Energy Policy* **2007**, *35*, 1701–1708. [CrossRef]
41. Kavouridis, K.; Koukouzas, N. Coal and sustainable energy supply challenges and barriers. *Energy Policy* **2008**, *36*, 693–703. [CrossRef]
42. Gawlik, L.; Mokrzycki, E. Changes in the structure of electricity generation in Poland in view of the EU climate package. *Energies* **2019**, *12*, 3323. [CrossRef]
43. Lund, P.D.; Skytte, K.; Bolwig, S.; Bolkesjo, T.F.; Bergaentzle, C.; Gunkel, P.A.; Kirkerud, J.G.; Klitkou, A.; Koduvere, H.; Gravelsins, A.; et al. Pathway analysis of a zero-emission transition in the Nordic-Baltic region. *Energies* **2019**, *12*, 3337. [CrossRef]
44. Ahmad, T.; Zhang, D. A critical review of comparative global historical energy consumption and future demand: The story told so far. *Energy Rep.* **2020**, *6*, 1973–1991. [CrossRef]
45. Antosiewicz, M.; Nikas, A.; Szpor, A.; Witajewski-Baltvilks, J.; Doukas, H. Pathways for the transition of the Polish power sector and associated risks. *Environ. Innov. Soc. Transit.* **2020**, *35*, 271–291. [CrossRef]
46. Kittel, M.; Goeke, L.; Kemfert, C.; Oei, P.-Y.; von Hirschhausen, C. Scenarios for coal-exit in Germany—A model-based analysis and implications in the European context. *Energies* **2020**, *13*, 2041. [CrossRef]
47. Pena-Ramos, J.A.; del Pino-Garcia, M.; Sanchez-Bayon, A. The Spanish energy transition into the EU Green Deal: Alignments and paradoxes. *Energies* **2021**, *14*, 2535. [CrossRef]
48. Simeonovski, K.; Kaftandzieva, T.; Brock, G. Energy efficiency management across EU countries: A DEA approach. *Energies* **2021**, *14*, 2619. [CrossRef]
49. Daroń, M.; Wilk, M. Management of energy sources and the development potential in the energy production sector—A comparison of EU countries. *Energies* **2021**, *14*, 685. [CrossRef]
50. Gostkowski, M.; Rokicki, T.; Ochnio, L.; Koszela, G.; Wojtczuk, K.; Ratajczak, M.; Szczepaniuk, H.; Bórawski, P.; Bełdycka-Bórawska, A. Clustering Analysis of Energy Consumption in the Countries of the Visegrad Group. *Energies* **2021**, *14*, 5612. [CrossRef]
51. Halkos, G.; Tsilika, K. Visual exploration of energy use in EU 28: Dynamics, patterns, policies. *Energies* **2021**, *14*, 7532. [CrossRef]
52. Kasztelan, A. On the road to a Green Economy: How do European Union countries 'Do their homework'? *Energies* **2021**, *14*, 5941. [CrossRef]
53. Sipa, M.; Gorzeń-Mitka, I. Assessment of the progress towards the management of renewable energy consumption in the innovativeness context—A country approach. *Energies* **2021**, *14*, 5064. [CrossRef]
54. Hwang, C.-L.; Yoon, K. *Multiple Attribute Decision Making*, 1st ed.; Springer-Verlag: Berlin/Heidelberg, Germany, 1981; pp. 128–132.
55. Jajuga, K.; Walesiak, M.; Bak, A. On The General Distance Measure. In *Exploratory Data Analysis in Empirical Research*; Schwaiger, M., Opitz, O., Eds.; Springer: Berlin/Heidelberg, Germany, 2003; pp. 104–109.
56. Walesiak, M. *Uogólniona Miara Odległości GDM w Statystycznej Analizie Wielowymiarowej z Wykorzystaniem Programu R*, 2nd ed.; Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu: Wrocław, Poland, 2016; p. 43.
57. Grabiński, T. *Metody Taksonometrii*; Wydawnictwo Akademii Ekonomicznej w Krakowie: Kraków, Poland, 1992; pp. 101–111.
58. Eurostat Database. Stock Levels for Oil Products. Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_stk_oil/default/table?lang=en (accessed on 1 October 2021).

59. Eurostat Database. Population on 1 January by Age and Sex. Available online: https://ec.europa.eu/eurostat/databrowser/view/demo_pjan/default/table?lang=en (accessed on 1 October 2021).
60. Eurostat Database. Share of Fossil Fuels in Gross Available Energy. Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ffgae/default/table?lang=en (accessed on 1 October 2021).
61. Eurostat Database. Supply, Transformation and Consumption of Solid Fossil Fuels. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_SFF__custom_2742493/default/table?lang=en (accessed on 1 October 2021).
62. Eurostat Database. Production of Electricity and Derived Heat by Type of Fuel. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_BAL_PEH__custom_2742647/default/table?lang=en (accessed on 1 October 2021).
63. Eurostat Database. Stock Levels for Gaseous and Liquefied Natural Gas. Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_stk_gas/default/table?lang=en (accessed on 1 October 2021).
64. Eurostat Database. Share of Fuels in Final Energy Consumption. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_IND_FECF__custom_2743065/default/table?lang=en (accessed on 1 October 2021).
65. Eurostat Database. Simplified Energy Balances. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_BAL_S__custom_3041423/default/table?lang=en (accessed on 1 October 2021).
66. Eurostat Database. Solar Thermal Collectors' Surface. Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_inf_stcs/default/table?lang=en (accessed on 1 October 2021).
67. Eurostat Database. Liquid Biofuels Production Capacities. Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_inf_lbpc/default/table?lang=en (accessed on 1 October 2021).
68. Eurostat Database. Electricity Production Capacities for Renewables and Wastes. Available online: https://ec.europa.eu/eurostat/databrowser/view/nrg_inf_epcrw/default/table?lang=en (accessed on 1 October 2021).
69. Eurostat Database. Complete Energy Balances. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_BAL_C__custom_2743696/default/table?lang=en (accessed on 1 October 2021).
70. Government of the Republic of Poland. Available online: https://www.gov.pl/web/polski-atom/bezpieczenstwo-energetyczne-podstawa-rozwoju-spoleczenstwa (accessed on 1 July 2022).
71. Sun, C.; Negro, E.; Vezzu, K.; Pagot, G.; Cavinato, G.; Nale, A.; Bang, Y.H.; di Noto, V. Hybrid inorganic-organic proton-conducting membranes based on SPEEK doped with WO3 nanoparticles for application in vanadium redox flow batteries. *Electrochim. Acta* **2019**, *309*, 311–325. [CrossRef]
72. Wang, W.; Tai, G.; Pei, J.; Pavesi, G.; Yuan, S. Numerical investigation of the effect of the closure law of wicket gates on the transient characteristics of pump-turbine in pump mode. *Renew. Energy* **2022**, *194*, 719–733. [CrossRef]
73. Sun, C.; Zhang, H. Review of the Development of First-Generation Redox Flow Batteries: Iron-Chromium System. *ChemSusChem* **2022**, *15*, e202101798. [CrossRef]