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The Development of Renewable Energy Sources in the European Union in the Light of the European Green Deal

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Abstract: Climate and energy policies are the key areas of the European Union's development aspirations in the international arena. The European Green Deal sets ambitious new goals in this respect, emphasizing clean energy. The development of the energy sector, relying chiefly on renewable sources, is one of the conditions for the EU to transition to energies that do not produce waste that pollutes or is otherwise harmful to the Earth and human health. This paper assesses the development of renewable sources of energy in the EU and identifies challenges to the realization of the EU's energy priorities. An analysis of renewable sources of energy in the EU in 2012 and 2020 is the prime method. The generation of primary energy from renewable sources, the share of energy from renewable sources in the final energy consumption, the structure of energy generation from renewable sources, and the share of energy from renewable sources in the energy used by the transport sector are discussed. Secondary data are employed, made available by Eurostat and Statistics Poland. To reach the objective of the study, Z. Hellwig's taxonomic method is applied to assess the development of renewable energy sources (RES). Cluster analysis (Ward's agglomerative clustering method) is additionally used for separation of objects and member states that are similar with regard to the phenomenon reviewed. Particular attention is paid to the challenges that societies and economies face in view of the assumptions of the EU's new Green Deal, which envisages a balancing of CO_2 emissions and absorption. This analysis discovers varied progress on the development of RES in the member states, posing a threat to the European community's aspirations.

Keywords: climate and energy policy; renewable energy sources; European Green Deal; Hellwig's method; Ward's method

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1. Introduction

Energy is an essential resource for the development of economies and a high quality of life of societies; therefore, the demand for energy is constantly increasing. However, this poses a threat to the environment and the well-being of future generations [1]. Consequently, the development of the energy sector based primarily on renewable sources is one of the conditions for the European Union's transition to energies that do not produce polluting or harmful waste for the Earth and human health.

So far, many publications have been published in the field of production and consumption of energy from renewable sources in the EU countries in the context of the European community's energy and climate policy. In this research, there is a shortage of studies showing the differentiation of member states in terms of achieving community goals for RES development and the classification of the European Union countries by levels of renewable energy development. The study attempts to fill the research gap by identifying the disparities in the level of development of RES in the member states, which may pose a threat to the realization of the community's growing aspirations in this area. Thus, the aim of this article is to assess the development of RES in the EU and to identify the challenges in meeting energy priorities of the EU.

2. EU Development Assumptions for the Development of Renewable Energy Sources

The Treaty on the Functioning of the European Union (TFEU Art. 194) states that the promotion of RES is one of the objectives of the EU energy policy [2]. The increased use of renewable energy is caused by the fact that it is an important part of the package of measures needed to reduce greenhouse gas emissions and meet the EU's commitments under the 2015 Paris Agreement on climate change [3]. A detailed framework is defined by the EU's climate and energy policy until 2030, which assumes significant reductions in emissions.

In 2009, the EU set a goal that by 2020, 20% of the Community's energy consumption was to come from renewable sources. Since then, EU legislation to promote RES has evolved significantly to increase the thresholds of the goals set. In 2018, a goal for 2030 was agreed upon—by that time, 32% of energy consumption will come from renewable sources. In July 2021, in the wake of the EU's new climate ambitions, a revised goal was proposed in the European Green Deal implementation package. Discussions on binding goals beyond 2030 are also underway. In this context, the use of renewable fuels such as hydrogen in industry and transport is being promoted [4].

The 2018 Renewable Energy Directive clarifies ways to increase the role of RES in selected sectors of the economy: electricity, heating and cooling, transport, and bioenergy [5]. According to this, member states collectively ensure that the share of renewable energy in the EU's gross final energy consumption in 2030 is at least 32%. In order to meet the EU's overall goal for 2030, member states determine national contributions in their integrated national energy and climate plans. According to the directive, gross final consumption of energy from renewable sources in each member state is calculated as the sum of final consumption of the following: gross electricity from renewable sources, gross consumption of energy from renewable sources in the heating and cooling sector, and from renewable sources in the transport sector.

The most important document defining the EU's priorities in the area of climate and energy policy is the European Green Deal (EGD), which is the EU's updated commitment to address climate and environmental challenges [6]. The genesis for its creation is the search for solutions to the problems facing today's generation associated with climate change, warming, environmental pollution, and loss of biodiversity, through the development of the European climate law [7]. Ecosystems, people, and economies in all regions of the EU are vulnerable to extreme heat, floods, droughts, water shortages, rising sea and ocean levels, melting glaciers, forest fires, windfalls, and agricultural losses, so the European Green Deal seeks to separate economic growth from resource consumption [8]. In the package presented by the European Commission on 11 December 2019, it is assumed that Europe will become a climate-neutral continent by 2050. However, the European Green Deal goes beyond a strict climate-environmental framework, as it is the EU's new growth strategy, which aims to transform the EU into a just and prosperous society, living in a modern and resource-efficient economy. The document is also an integral part of the European Commission's strategy for achieving the UN 2030 Agenda for Sustainable Development and the Sustainable Development Goals. Nearly 50 different initiatives and activities in key sectors for the development of modern economies are scheduled for implementation in the EGD. It assumes, among other things, building and renovating in ways that conserve energy and resources, protecting and restoring ecosystems and biodiversity, accelerating the transition to sustainable and intelligent mobility, and creating a healthy, environmentally friendly food system called "farm to fork" [6].

Promoting the use of renewable energy is also a key area of implementation of the EGD. Under the provisions of the EGD, the provision of clean, affordable, and secure energy has become a fundamental task of the EU. Renewable energy sources (wind energy, solar energy, hydroelectric energy, ocean energy, geothermal energy, biomass, and biofuels) are alternatives to fossil fuels and contribute to reducing greenhouse gas emissions [9], diversifying energy supplies, and reducing dependence on uncertain and volatile fossil fuel markets, especially oil and gas. The transition from the current energy system using non-renewable energy sources (fossil fuels) to an energy system based mainly on renewable and low or no carbon sources means a profound transformation [7,10–12]. Achieving the target will require action from all sectors of the EU economy [13,14]. It is essential to invest in environmentally friendly technologies, decarbonize the energy sector, make buildings more energy efficient, and introduce cleaner forms of private and public transport. Therefore, it is supported by support schemes for renewable electricity. Member states, in accordance with the 2018 directive, shall provide incentives for the introduction of electricity from renewable sources into the electricity market in a market-driven and market-responsive manner, avoiding unnecessary distortions of electricity markets and taking into account the potential costs of inclusion in the system and network stability. It is worth noting that the Renewable Energy Directive [5], which is part of the "Clean Energy for All Europeans" package, aims to maintain the European Union's position as a global leader in RES.

The implementation of the EGD brought modifications to its assumptions. The level of ambition of the community in meeting the 2030 climate goal has increased. In July 2021, a new energy legislative package was introduced: "Fit for 55: delivering the EU's climate target on the way to climate neutrality". The new revision of the Renewable Sources Directive proposes raising the binding target for the share of RES in the energy mix to 40% by 2030. The following new targets at the member state level are also included:

- A new benchmark of 49% renewable energy use by 2030 in buildings;
- A new benchmark of 1.1 percentage point of annual growth in renewable energy use in industry;
- A binding annual increase of 1.1 percentage point for member states in the use of RES for heating and cooling;
- An indicative annual increase of 2.1 percentage points for the use of RES and waste-to-energy heating and cooling for urban heating and cooling [4].

Furthermore, the transportation sector must be decarbonized and diversified by reducing the intensity of greenhouse gas emission from transport fuels by 13% by 2030. In addition, the following was assumed:

- A 2.2 percent share of advanced biofuels and biogas, with an interim target of 0.5% by 2025;
- A target of 2.6% for non-biological renewable fuels and a 50% share of renewable energy in hydrogen consumption in the industry, including non-energy applications, by 2030 [4].

The aim of the study was to analyze and evaluate the level of RES development in the EU in 2012 and 2020.

3. Methods

In order to compare the level of development of RES of the EU countries, this paper uses Hellwig's taxonomic measure of development [15,16] and Ward's method [17]. The first one belongs to the methods of linear ordering, which is based on the synthetic quantity, which is the resultant of all variables adopted for the study. This method is classified as a pattern method, which means that the ordering of the studied objects is carried out taking into account the pattern of development. This makes it possible to identify the level of development and create comparative rankings [18].

A set of diagnostic variables that characterize the phenomenon under study was used to assess the potential of RES. This selection meets three basic criteria: substantive, formal, and statistical [19]. Taking into account the achievements of the researchers on the subject and the experience of the authors of the article in this area, the features for examining the RES potential of the EU countries were identified. A matrix of nine explanatory variables was prepared to conduct this analysis. The selection of variables adopted for the study was determined by the subjective assessment of the impact of individual indicators on the phenomenon under study, as well as the possibility of obtaining statistical data The Eurostat database became a basic source of information and the International Renewable Energy Agency IRENA database [20,21] were a complementary source. As explained in the Eurostat database, the data in question are complete and comparable across countries in accordance with the Renewable Energy Directive 2009/28/EC.

3.1. Hellwig's Method

The first stage in the construction of Hellwig's taxonomic measure is the selection of diagnostic variables, forming the input matrix of indicators used in the study. Essential to the application of the development pattern method is the determination of features of the variables, i.e., whether they are stimulants or destimulants. In this study, only stimulants form variables.

In order to carry out further computational work, it is necessary to standardize the values of individual indicators, which allows one to obtain comparability of diagnostic features by changing their natural units. All variables are stimulants. For this purpose, normalization of features was applied through classic standardization of variable value according to the following formula:

$$Z_{ik} \frac{x_{ik} - \overline{x}_k}{S_k} \quad \text{for } x_k \in I;\ i = 1,\ \ldots,\ n;\ k = 1, \ldots,\ m \tag{1}$$

where:

Z_{ik}—standardized value of feature k for country i;
I—set of stimulants;
x_{ik}—value of feature k in country i;
$\overline{x}_k$—arithmetic mean of variable k;
S_k—standard deviation of variable k;
m—number of variables;
n—number of countries.

The standardization was carried out taking into account the arithmetic mean and standard deviation was calculated based on all variables determined for the whole research period. Thus, the synthetic measure of innovativeness can be comparable over time. In this way, the analysis takes on a dynamic character [22].

In the next step, a development pattern was determined, defined as abstract object P_0, which is characterized by the highest values for stimulants and has standardized coordinates:

$$P_0 = [Z_{01},\ Z_{02},\ \ldots, Z_{0k,}] \tag{2}$$

where:

$$Z_{0k} = \max\{Z_{ik}\}\ when\ x_{ik}\ is\ a\ stimulant$$

On the basis of Equation (3), distances between regions (EU countries) and P_0 pattern (Euclidean distance) were calculated:

$$c_{i0} = \sqrt{\sum_{k=1}^{m} (z_{ik} - z_{0k})^2} \quad i = 1, 2, 3, \ldots,\ n \tag{3}$$

In order to normalize the value of synthetic indicator (d_i), a relative taxonomic measure of development was constructed, which was calculated according to the following formula:

$$d_i = 1 - \frac{c_{i0}}{c_0} \quad i = 1, 2, 3, \ldots,\ n \tag{4}$$

where:

$$c_0 = \bar{c}_0 + 2 * s_0 \quad (5)$$

$\bar{c}_0$—arithmetic mean of c_{i0} (i = 1, 2, 3, ... n) sequence;
s_0—standard deviation of c_{i0} (i = 1, 2, 3, ... n) sequence.

Whereas:

$$\bar{c}_0 = \frac{1}{n} \cdot \sum_{i=1}^{n} (c_{i0} - \bar{c}_0)^2 \quad (6)$$

and

$$s_0 = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (c_{i0} - \bar{c}_0)^2} \quad (7)$$

The synthetic measure of development d_i (4) obtained as a result of the calculations assumes values in the range from 0 to 1. Its upper limit is 1, while the probability of it being less than 0 is small. The closer the value of the d_i measure is to 1, the less distant the object (in this case the EU country) is from the pattern and the higher the level of RES development.

By calculating a synthetic indicator, it is possible to prioritize the objects—that is, countries—in terms of potential within the scope of RES. A scheme for classifying countries into different groups indicating the level of RES development was constructed using arithmetic mean and standard deviation. The groups of countries with the highest, high, low, and very low levels of RES development were distinguished according to the following ranges [22,23]:

Group I—countries with the highest level of RES development: $d_i \geq \overline{d_i} + S_{di}$;
Group II—countries with high level of RES development: $\overline{d_i} \leq d_i < \overline{d_i} + S_{di}$;
Group III—countries with low level of RES development: $\overline{d_i} - S_{di} \leq d_i < \overline{d_i}$;
Group IV—countries with very low level of RES development: $d_i < \overline{d_i} - S_{di}$.

where:

d_i—arithmetic mean of the synthetic indicator;
S_{di}—standard deviation of the synthetic indicator.

3.2. Ward's Method

The analysis of RES potential is complemented by the classification of the European Union countries by similar level of development of RES using cluster analysis. It assumes the segmentation of data in order to extract homogeneous objects from the studied population. Hence the division of a group into individual groups is carried out in such a way as to obtain clusters in which the elements in the same group are similar to each other and at the same time different from the elements in the other groups [24].

Ward's method, which is one of the hierarchical methods of object classification, was used to group countries of the European Union into clusters. It differs from other hierarchical methods in that the analysis of variance is used to determine the distance between clusters. Minimizing the sum of squares of deviations within clusters is key in the application of this method. Thus, Ward's method ensures homogeneity within clusters and heterogeneity between clusters, and therefore is considered to be most effective. It should be stressed, however, that it tends to combine a relatively small number of observations and to distinguish clusters of similar size [17,19,25,26].

The study was carried out on the basis of standardized variables, and the Euclidean distance was used to form clusters. The effects of using the Ward method are presented in the form of a cluster tree, i.e., dendrograms (using Statistica 13.3). Analysis using Ward's method made it possible to combine the EU countries that are the most similar to each other and that are, at the same time, maximally different from each other in terms of the distinguished features determining the level of development. In the conducted study, a critical value was determined on the basis of the analysis of the graph of the course of agglomerations. After observing the largest increment, in which numerous clusters are formed approximately at the same connectivity distance, there is a cut-off dividing the set into classes.

3.3. Variables Adopted for the Studies

All characteristics, which are the basis for the preparation of a synthetic indicator in Hellwig's method, were presented in relative values. This gives the values of each variable a more in-depth reflection of their scale and importance in shaping RES development in a given country. The level of RES development is largely characterized by features, as in Table 1.

x_1—share of energy from renewable sources in total primary energy (%);
x_2—share of renewables in gross final energy consumption (%);
x_3—share of renewable energy in final energy consumption in transport (%);
x_4—share of electricity from renewable sources in gross final electricity consumption (%);
x_5—share of energy from renewable sources in heating and cooling (%);
x_6—installed capacity of wind energy (%);
x_7—installed capacity of solar energy (%);
x_8—installed capacity of bioenergy (%);
x_9—installed capacity of hydropower (%).

Table 1. Selected diagnostic features concerning the RES development level of EU countries in the years 2012 and 2020.

EU Countries	Feature								
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
					2012				
Belgium	18.0	7.09	4.92	11.34	7.11	26.7	51.7	19.3	2.3
Bulgaria	14.0	15.84	0.65	15.82	27.24	16.8	25.2	0.3	57.6
Czechia	10.2	12.81	6.25	11.67	16.25	6.5	50.6	16.4	26.6
Denmark	16.5	25.47	6.28	38.72	33.20	70.0	6.8	23.1	0.2
Germany	26.6	13.55	7.32	23.61	13.42	39.6	43.6	9.6	7.2
Estonia	20.7	25.59	0.45	15.67	43.22	60.3	0.1	37.8	1.8
Ireland	57.8	7.03	4.04	19.84	4.85	85.3	0.0	2.9	11.9
Greece	21.8	13.74	0.90	16.36	24.12	26.7	23.4	0.7	49.2
Spain	43.7	14.24	0.87	33.44	13.97	49.1	14.1	2.1	34.6
France	15.6	13.24	7.42	16.55	16.59	20.5	11.8	2.9	64.3
Croatia	34.2	26.76	1.05	38.76	36.55	7.7	0.2	0.8	91.4
Italy	56.3	15.44	6.16	27.42	16.98	17.3	35.9	6.8	38.4
Cyprus	100.0	7.11	0.00	4.93	21.76	85.0	9.8	5.2	0.0
Latvia	99.8	35.71	4.00	44.88	47.27	3.5	0.0	3.9	92.6
Lithuania	90.8	21.44	4.97	10.88	34.54	61.0	1.6	11.7	25.7
Luxembourg	74.5	3.11	2.83	4.66	4.93	31.2	39.9	10.5	18.4
Hungary	18.7	15.53	6.00	6.06	23.31	44.9	1.7	45.7	7.7
Malta	100.0	2.86	3.22	1.12	13.40	0.5	83.5	16.0	0.0
Netherlands	5.8	4.66	5.22	10.35	3.77	70.1	8.3	20.6	1.1
Austria	75.3	32.73	10.03	67.44	33.08	8.0	2.0	9.9	79.9
Poland	11.9	10.96	6.53	10.61	13.50	62.6	0.0	14.2	23.1
Portugal	94.8	24.57	0.81	47.51	33.15	40.3	2.2	5.2	52.1
Romania	19.2	22.83	4.96	33.57	25.75	21.8	0.5	0.5	77.3
Slovenia	27.9	21.55	3.25	31.64	33.15	0.2	11.1	4.6	84.1
Slovakia	23.0	10.45	5.60	20.05	8.80	0.1	22.0	9.1	68.8
Finland	58.1	34.22	1.05	29.11	48.23	4.9	0.2	35.8	59.1
Sweden	51.8	49.40	13.78	59.78	60.64	14.9	0.1	17.9	67.2
Arithmetic average	44.0	18.1	4.4	24.1	24.4	32.4	16.5	12.4	38.6
Standard deviation	32.12	11.22	3.23	17.08	14.82	27.12	21.45	11.99	31.99
Coefficient of variation	73.07	62.09	73.67	70.75	60.75	83.63	129.77	97.06	82.84

Table 1. *Cont.*

EU Countries	Feature								
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
				2020					
Belgium	29.9	13.00	11.04	25.12	8.45	41.4	49.9	8.2	0.9
Bulgaria	23.8	23.32	9.10	23.59	37.18	16.1	25.2	1.1	57.6
Czechia	22.1	17.30	9.38	14.81	23.54	7.7	48.2	19.2	24.9
Denmark	45.6	31.68	9.70	65.32	51.07	66.9	13.9	19.1	0.1
Germany	47.5	19.31	9.92	44.70	14.81	47.2	40.8	7.9	4.2
Estonia	42.0	30.07	12.17	28.29	58.83	38.3	25.1	35.7	1.0
Ireland	45.5	16.16	10.19	39.06	6.26	90.8	2.0	2.3	5.0
Greece	64.8	21.75	5.34	35.86	31.94	37.7	30.1	0.9	31.3
Spain	55.4	21.22	9.53	42.94	17.97	46.7	21.9	2.2	29.2
France	22.8	19.11	9.21	24.82	23.37	31.5	21.6	3.3	43.2
Croatia	62.3	31.02	6.59	53.82	36.93	24.6	3.3	4.2	67.6
Italy	72.6	20.36	10.74	38.08	19.95	19.6	39.0	6.2	33.8
Cyprus	96.3	16.88	7.40	12.04	37.12	39.5	57.3	3.2	0.0
Latvia	99.3	42.13	6.73	53.36	57.09	4.3	0.3	8.6	86.9
Lithuania	83.9	26.77	5.51	20.17	50.35	52.0	23.9	12.9	11.3
Luxembourg	85.3	11.70	12.58	13.89	12.61	35.5	43.4	13.0	8.0
Hungary	29.3	13.85	11.57	11.90	17.72	10.6	70.5	16.8	1.9
Malta	100.0	10.71	10.59	9.49	23.03	0.1	97.6	2.4	0.0
Netherlands	26.0	14.00	12.63	26.41	8.05	35.8	59.3	4.7	0.2
Austria	84.9	36.55	10.28	78.20	35.00	15.3	9.7	6.0	69.1
Poland	21.6	16.10	6.58	16.24	22.14	51.3	32.2	8.5	8.0
Portugal	98.0	33.98	9.70	58.03	41.55	36.1	7.7	5.0	51.0
Romania	25.9	24.48	8.54	43.37	25.33	27.1	12.4	1.5	59.0
Slovenia	30.8	25.00	10.91	35.10	32.14	0.2	22.9	4.1	72.7
Slovakia	32.3	17.35	9.26	23.07	19.43	0.1	22.5	9.6	67.9
Finland	64.4	43.80	13.44	39.56	57.62	29.4	3.6	30.8	36.1
Sweden	62.8	60.12	31.85	74.50	66.38	31.2	3.5	13.9	51.3
Arithmetic average	54.6	24.4	10.4	35.2	31.0	31.0	29.2	9.3	30.5
Standard deviation	27.38	11.47	4.79	19.19	17.06	21.27	23.61	8.76	28.32
Coefficient of variation	50.11	47.09	46.11	54.43	55.12	68.61	80.90	94.09	93.00

Source: own elaboration based on [20,21].

The share of renewable energy in total energy production (x_1) indicates how widespread the generation of energy from unconventional sources is and, consequently, the extent to which renewable fuels are replacing fossil and nuclear fuels. Primary energy production is the extraction of energy products in a usable form from natural resources, i.e., wherever natural resources are used, e.g., in coal mines, in oil fields, in hydroelectric power plants, or in the production of biofuels. Indicator x_2 measures the share of renewable energy consumption in the gross final energy consumption. The gross final energy consumption is the energy consumed by end users (final energy consumption) plus network losses and power plants' own consumption. The gross final energy consumption therefore means energy commodities supplied for energy purposes to industry, the transport sector, households, the tertiary sector, agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy industry for electricity and heat generation, and including losses of electricity and heat during distribution and transmission. Indicators x_3, x_4, and x_5 complete the analysis of the total share of renewable energy. These are indicators for the share of RES in three sectors of consumption: electricity, heating and cooling, and transport. These indicators are part of a set of indicators for the EU Sustainable Development Goals and monitor progress towards achievement of the seventh Sustainable Development Goal on affordable and clean energy and the thirteenth Sustainable Development Goal on climate action, which are embedded in the priorities of the "European Green Deal". Thus, the share of electricity from RES is defined as the ratio of electricity generated from RES to gross national electricity consumption. The gross final consumption of electricity from RES is electricity generated from RES; it includes: hydroelectric power plants (excluding hydroelectricity generated from pumped-storage power stations using water previously pumped uphill) and electricity generated from solid biofuels/waste, wind, solar, and geothermal facilities. For the calculation of the share of energy from renewable sources in heating and cooling, the final consumption of energy from renewable sources is defined by Eurostat as the final consumption of energy from renewable sources in industry, households, services, agriculture, forestry, and fisheries for heating and cooling and district heating produced from renewable sources. In turn, total final consumption for heating and cooling is the final consumption of all energy commodities, except electricity, for purposes other than transport, plus the consumption of heat for use in combined heat and power plants and heating plants, as well as heat losses in networks. The indicator of the share of RES in transport has been used to monitor progress in implementation of the goals of the Europe 2020 strategy and currently the European Green Deal within the scope of energy from renewable sources. The other indicators—x_6, x_7, x_8 and x_9—relate to the development of renewable energy in the context of the feasibility of its use, with a focus on sources.

The empirical analysis was conducted based on the ability to access the source materials. The study covered all EU countries and was based on statistics obtained for 2012 and 2020. The variables selected as diagnostic variables should be characterized by high diversity and low correlation with other variables [27]. In order to obtain the final set of variables, a reduction was performed on the basis of the coefficient of variation, Hellwig's parametric method [15], and the following studies: [25,26]. The threshold value of Pearson's correlation coefficient was arbitrarily set as $r^* = 0.8$. From the initial set of variables, those for which the determined coefficient of variation is less than the assumed threshold value are eliminated. In the present case, the coefficient of variation for all analyzed variables was higher than 10%, which means that the selected diagnostic characteristics have a high capacity to differentiate EU member states due to their potential to generate RES. The determination of the correlation matrix of the variables allowed us to analyze their information capacity. In this study, Pearson's linear correlation coefficient was chosen to assess the degree of correlation between the variables, assuming that features have relatively high variability if the correlation coefficient takes values higher than 0.8. An arbitrarily set value for the correlation coefficient was adopted and elimination of features was done on the basis of substantive reasons. Based on Hellwig's parametric method, variable x_5 (satellite variable) was excluded from the study. Ultimately, eight diagnostic variables were adopted to achieve the objective of the study, where x_2 is a central variable and: x_1, x_3, x_4, x_6, x_7, x_8, and x_9 are isolated variables. On the basis of the analysis carried out in the selection of diagnostic characteristics, it can be concluded that the final set includes variables characterized by a high ability to discriminate individuals in the analyzed area. This implies their high spatial variability and low degree of correlation among themselves. Thus, variables carrying similar information were removed.

4. Results

4.1. Level of Development of RES of the European Union Countries on the Basis of Hellwig's Indicator

The calculated Hellwig indicators show the distances from the benchmark and thus higher or lower levels of RES development. At the same time, they make it possible to determine the distance separating EU member states in terms of renewable energy sources.

On the basis of Hellwig's synthetic development pattern indicator, countries were classified into four groups: those with the highest, high, low, and very low potential in scope of renewable sources of energy. The results obtained indicate significant disproportions in the level of development of RES of the EU member states, which is illustrated in Table 2 and Figure 1.

According to Hellwig's development pattern method, in both 2012 and 2020, the group of countries with the highest level of RES development were Sweden and Denmark, with Austria also in the group in 2012 and Finland and Estonia joining in the second year under study.

A particularly favorable change in the development of RES concerns Greece, Bulgaria, and Cyprus, which obtained the highest increases in the synthetic indicator, by 0.132 (advancement by four places), 0.125 (advancement by two places), and 0.145 (advancement by five places), respectively. A negative change was noted for Hungary (down from 10th to 17th position), Czechia (down from 11th to 18th position), and France (down from 16th to 22nd position), despite a slight increase in the Hellwig indicators by 0.063, 0.066, and 0.072, respectively.

Table 2. Synthetic indicator of the RES development level of EU countries in 2012 and 2020 based on Hellwig's taxonomic measure of development.

2012			2020		
Ranking Position	**Country**	**Indicator Value**	**Ranking Position**	**Country**	**Indicator Value**
Group of countries with the highest level of RES development					
$di \geq 0.189$			$di \geq 0.295$		
1.	Sweden	0.339	1.	Sweden	0.459
2.	Austria	0.260	2.	Finland	0.359
3.	Denmark	0.201	3.	Estonia	0.310
			4.	Denmark	0.300
Group of countries with a high level of RES development					
$0.121 \leq di < 0.189$			$0.224 \leq di < 0.295$		
4.	Italy	0.167	5.	Austria	0.284
5.	Finland	0.167	6.	Portugal	0.279
6.	Germany	0.165	7.	Italy	0.250
7.	Latvia	0.161	8.	Germany	0.247
8.	Lithuania	0.152	9.	Latvia	0.227
9.	Portugal	0.145	10.	Spain	0.226
10.	Hungary	0.127	11.	Luxembourg	0.226
11.	Czechia	0.122			
Group of countries with a low level of RES development					
$0.053 \leq di < 0.121$			$0.152 \leq di < 0.224$		
12.	Estonia	0.114	12.	Croatia	0.210
13.	Belgium	0.108	13.	Lithuania	0.210
14.	Romania	0.106	14.	Netherlands	0.203
15.	Poland	0.098	15.	Belgium	0.198
16.	France	0.097	16.	Slovenia	0.197
17.	Slovenia	0.095	17.	Hungary	0.190
18.	Slovakia	0.093	18.	Czechia	0.188
19.	Spain	0.091	19.	Romania	0.186
20.	Croatia	0.077	20.	Greece	0.181
21.	Luxembourg	0.076	21.	Ireland	0.170
22.	Netherlands	0.070	22.	France	0.169
23.	Ireland	0.069	23.	Cyprus	0.169
24.	Malta	0.066	24.	Bulgaria	0.164
			25.	Slovakia	0.162
Group of countries with very low levels of RES development					
$di < 0.053$			$di < 0.152$		
25.	Greece	0.049	26.	Poland	0.144
26.	Bulgaria	0.039	27.	Malta	0.136
27.	Cyprus	0.024			

Source: own elaboration based on [20,21].

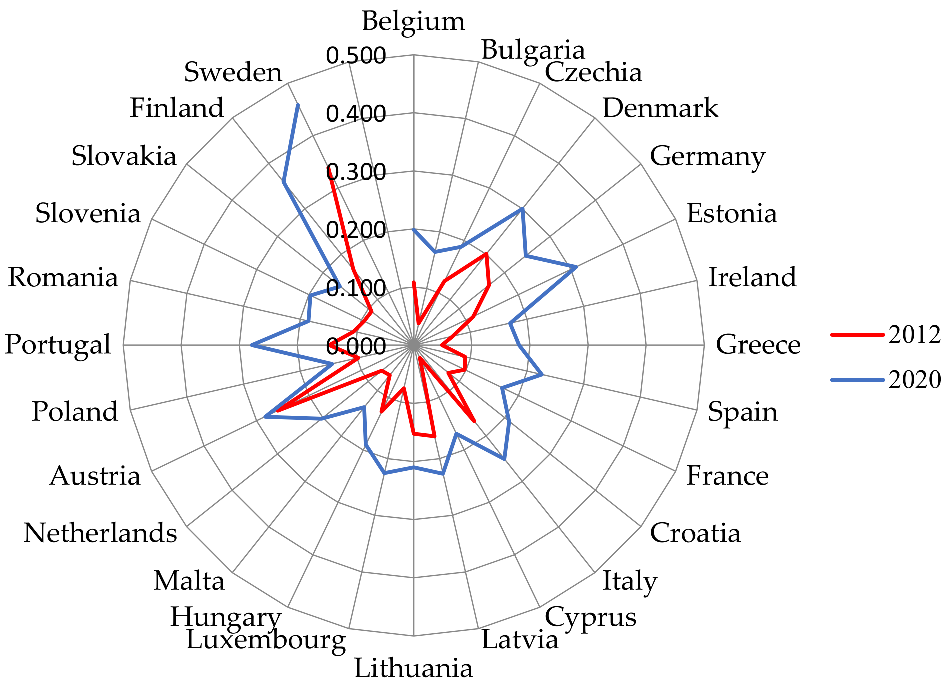

Figure 1. Distance of EU countries from the development pattern according to Hellwig's method in 2012 and 2020. Source: own study based on data from Table 1.

On the basis of Hellwig's synthetic development pattern indicator, EU countries were classified into four groups of regions: those with the highest, high, low, and very low levels of development of renewable sources of energy [22]. The results obtained indicate significant disparities in the level of potential within RES of the analyzed regions (Table 1 and Figure 1).

The countries with the best developed RES potential in 2012 were Sweden, Austria, and Denmark, with indicator values of 0.339, 0.260, and 0.201, respectively. In 2020, Austria left the group with the highest level of RES development and Finland and Estonia joined it. However, the small gap between countries in the group under discussion in 2012 (0.138) increased to 0.159 in 2020. The lowest level of RES development in 2012 was achieved by Cyprus, for which the synthetic measure took a value almost 14 times lower than the leader of the ranking, Sweden. It should be noted that the energy used in Sweden comes mainly from unconventional sources, and the most important sources of Swedish renewable energy are currently hydropower and biomass. In 2020, the gap between Malta and the country with the highest measure narrowed: the Hellwig indicator value for Malta was more than three times lower compared to Sweden. Thus, one can speak of quite significant spatial variations in the RES potential, which slightly increase with the passing of the analyzed years; that is, the gap between the leader and the last country in the ranking has slightly widened (in 2012: 0.315; in 2020: 0.323).

The group with high levels of RES development in 2012 consists of the following EU regions: Italy, Finland, Germany, Latvia, Lithuania, Portugal, Hungary, and Czechia. In 2020, this group decreased to seven countries, with only Italy, Germany, Latvia and Portugal remaining in this group and changing positions from fourth to seventh, sixth to eight, and seventh to ninth, respectively, with Portugal moving from ninth to sixth. The following regions were advanced to this group from countries with low levels of renewable energy development: Spain and Luxembourg, with Hellwig's indicator values of 0.226. In addition, Austria joined the group, leaving the group with the highest level of RES development, and although it experienced a drop of three places, its synthetic indicator increased by 0.02.

In 2012, 13 countries (Estonia, Belgium, Romania, Poland, France, Slovenia, Slovakia, Spain, Croatia, Luxembourg, Netherlands, Ireland, and Malta) had a low level of development potential in the field of RES, while in 2020, 14 countries made up the group. The unfavorable change characterizes the following countries: Lithuania, Hungary, and Czechia, which left the group with high RES development and recorded a decrease by five, seven, and seven positions, respectively. A particularly positive change took place for Estonia, which has left the group of low development and ranked third in the group with the highest level of development in terms of RES (moving up nine positions and increasing its value of Hellwig's indicator by 0.196). Poland and Malta, on the other hand, left Group III and were ranked 26th and 27th in the group of countries with very low RES development (down in the ranking by 11 and 3 positions, respectively).

In the first year analyzed, the group with low levels of potential development in the field of RES consisted of three countries, while in 2020, it decreased by one, with all countries from group IV in 2012 moving to the group with low potential in RES in 2020. Only Poland and Malta were in the fourth group, with synthetic indicator values of 0.144 and 0.136, respectively.

Significant variations in the spatial development of RES for EU countries are also highlighted by the fact that in both years under study, a comparable number of regions fell into the group of countries with the highest and high level of RES potential, i.e., 11 countries, and 16 fell into the group of countries with the lowest and low level of RES development, with the most countries in Group III in 2020 (14 regions in total).

4.2. Similarities of European Union Countries in the Development of RES Based on Ward's Method

To deepen the taxonomic analysis, cluster analysis was conducted to extract similar objects from a set of objects and group them together. It allows the capturing of the similarity of the structures of the studied countries due to the level of RES development. An agglomerative hierarchical method was used, grouping EU member states into increasingly large clusters (sets). An important element of cluster analysis is cutting off the dendrogram, which allows one to determine the number of clusters in the analyzed study. The analysis results in a dendrogram that is a graphical interpretation. In the conducted assessment of the level of RES development, an attempt was made to determine the critical value on the basis of the analysis of the linear connectivity distance graph in relation to subsequent stages of the connecting process. The cutoff point, i.e., the first point with the largest change in connectivity distance, was used for the study. This means that the clusters are distant. The Ward analysis conducted made it possible to distinguish similar objects, i.e., EU countries, in terms of the level of RES development.

On the basis of the analysis of the graph of the course of agglomeration for 2012, it can be concluded that the division of the dendrogram should be on the 24th step (Figure 2), i.e., the connectivity distance is located between six and eight, which in each case means the same number of EU country groups.

The following groups were formed in the EU country classification: two five-element groups, an eight-element group, and a nine-element group. The following five countries formed the first group: Sweden, Austria, Finland, Portugal, and Latvia. The separation of this group appears to depend largely on membership in countries with high and the highest level of RES development (based on Hellwig's method). Finland and Latvia are among the countries with the highest level of RES development, while Sweden and Austria are among the countries with high levels of RES development. The second cluster consists of Slovenia, Romania, Croatia, Italy, Spain, Slovakia, France, Greece, and Bulgaria. Most of these are countries with low levels of RES development. The structure of the third group, with five units, included Malta, Luxembourg, Cyprus, Lithuania, and Ireland. The fourth, eight-element cluster gathered the following EU countries: Poland, Netherlands, Hungary, Estonia, Denmark, Czechia, Germany, and Belgium. Within this most numerous cluster, the object-countries represent varying levels of RES development. A special case here is Denmark, which ranked among the countries with the highest level of RES development.

The analysis of the graph of the course of agglomeration for 2020 justifies the placement of the division of the dendrogram on the 24th step (Figure 4), i.e., the connectivity distance is between six and seven. For a connectivity distance of six, five clusters of relatively homogeneous objects, with counts of one, five, and eight, become apparent (Figure 5).

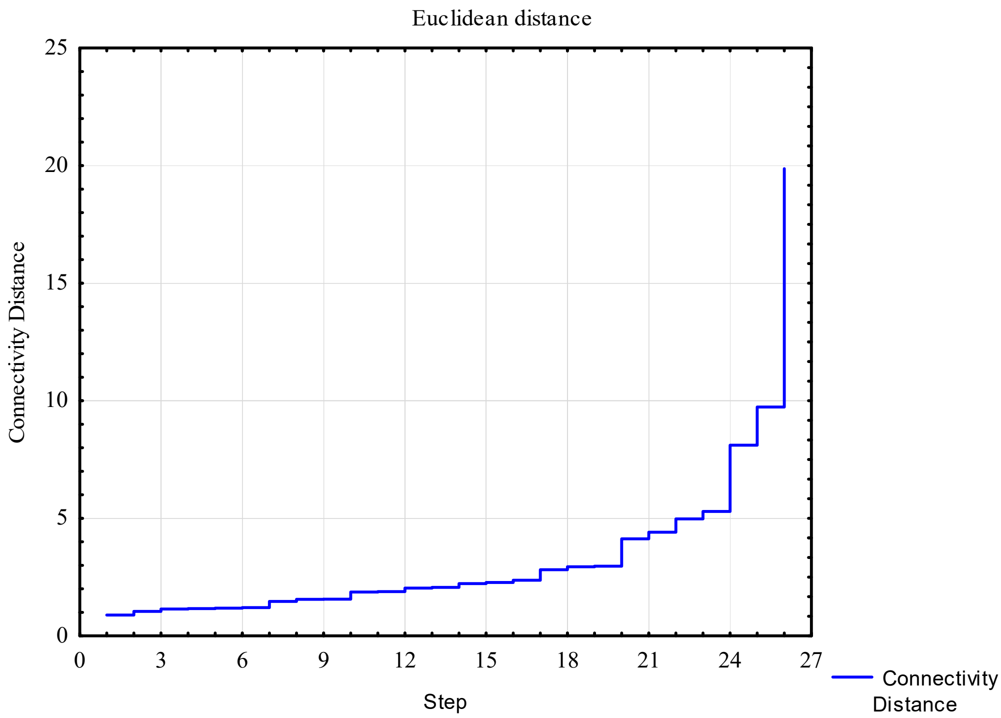

Figure 2. Diagram of the course of agglomeration for 2012. Source: author's own study.

On this basis, four clusters of varying size were identified in 2012. The connection tree for 2012 is shown in Figure 3.

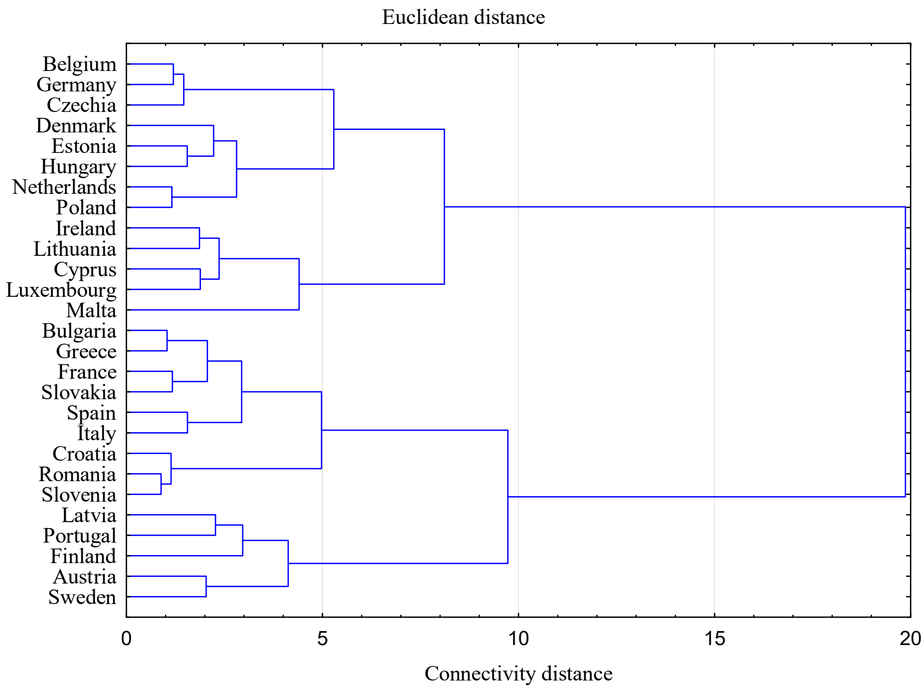

Figure 3. Clustering of EU countries with similar levels of RES development in 2012. Source: author's own study.

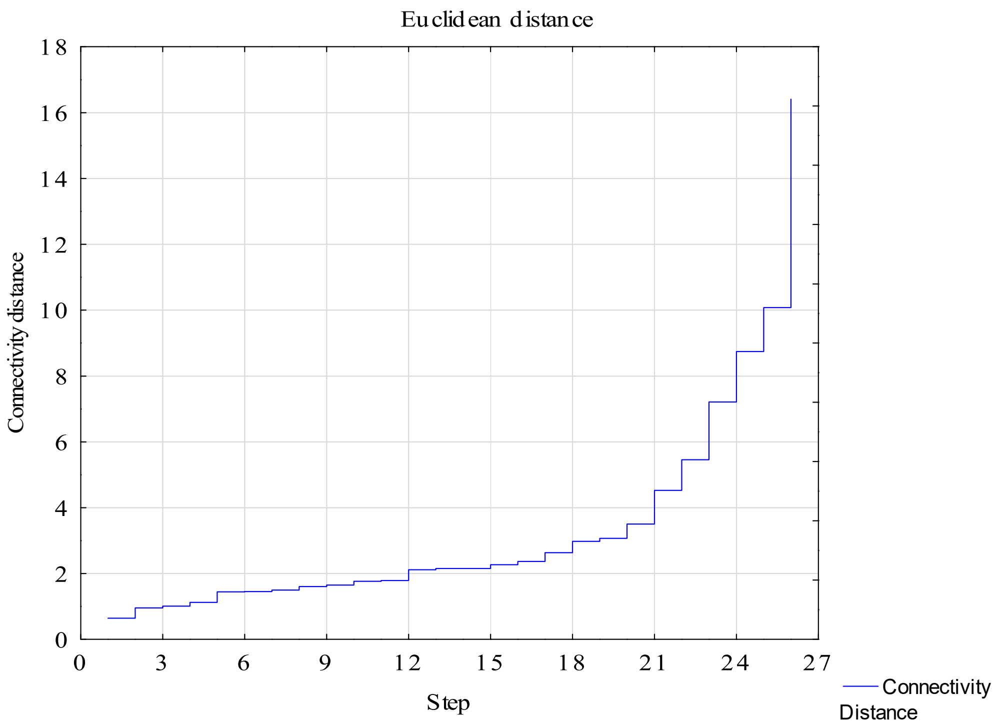

Figure 4. Diagram of the course of agglomeration for 2020. Source: author's own study.

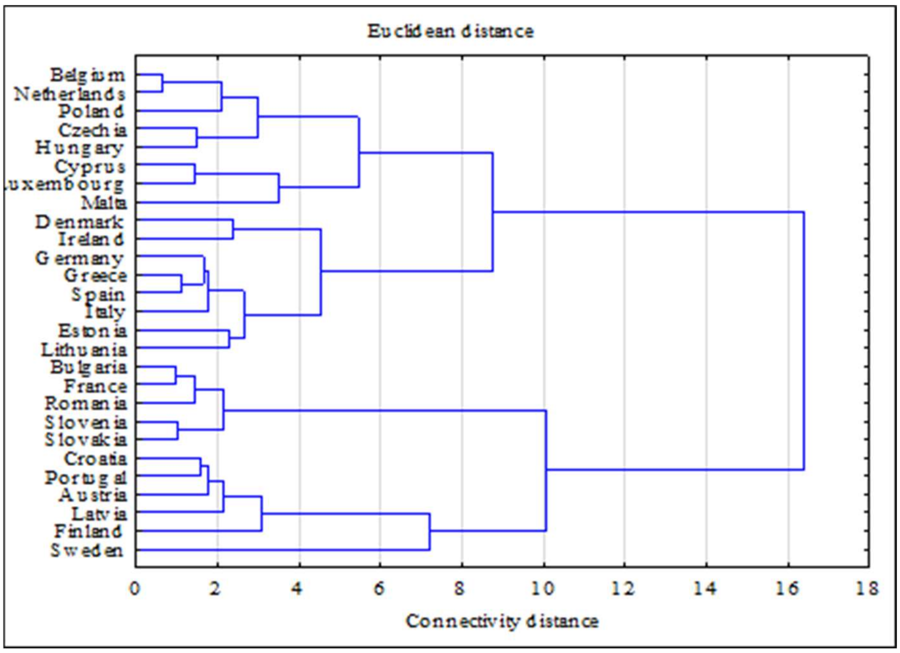

Figure 5. Similarity of EU countries in terms of the level of RES development in 2020 based on Ward's method. Source: author's own study.

The first of the eight-element clusters concentrates countries such as Malta, Luxembourg, Cyprus, Hungary, Czechia, Poland, the Netherlands, and Belgium. The second eight-element object class consists of Lithuania, Estonia, Italy, Spain, Greece, Germany, Ireland, and Denmark. The countries listed belong to the group with high or low RES development levels. The exception is Poland, where the synthetic indicator of RES development according to Hellwig's method reached the lowest value. Thus, Poland and Slovakia form the group with the lowest level of RES development in 2020. Two more clusters of five-elements are formed by, in the first set, Slovakia, Slovenia, Romania, France, and Bulgaria, and in the second set, Finland, Latvia, Austria, Portugal, and Croatia. It is noteworthy that the cluster of Slovakia, Slovenia, Romania, France, and Bulgaria were in the same class in 2012, with a slightly broader set of objects. This demonstrates the high similarity of structures. This can be confirmed by similar results achieved in RES development. In these countries, the share of RES in total energy production does not exceed 33%, placing them in the second half of the ranking of member states. On the other hand, in terms of the share of renewable energy in gross final energy consumption, these countries are in the middle positions of the ranking (between the 11th and 19th position). In their cluster, Finland, Austria, and Portugal represent the countries with the highest and high levels of RES development [12]. This cluster is also joined by Croatia from the group with low RES development, although it ranks first in the group in question. The last single-element cluster was formed by Sweden, whose Hellwig synthetic indicator ranked at the top of the EU countries. The difference in this cluster, it seems, has to do with the significant distance that separates this country from the next country in the ranking—Finland—which distances itself from the leader with an indicator value that is lower by 0.100.

5. Discussion

EU has adopted ambitious goals for the development of renewable energy, guided by the principle of sustainable development and climate protection, the changes of which have a number of negative consequences, mainly economic [28,29]. Mandatory goals for the EU and individual Member States have been adopted. According to the assumption, the share of renewable energy in gross final energy consumption was to be 20% on average in the EU in 2020. Member states were to contribute at varying degrees, ranging from 10% (Malta) to 49% (Sweden). In addition, each country was to ensure that renewable energy in all modes of transportation accounted for at least 10% of final energy consumption in transport in 2020. Significant changes are already visible in the EU countries, moving towards sustainability in the field of energy generation. Between 2012 and 2020, there was an increase in the share of energy generated from renewable sources in the energy consumption of the electricity, heating and cooling, and transportation sectors. The 2020 goal for RES development has been met by the European Union (22.1% against a goal of 20% share of RES). In most countries (23 EU countries), the share of RES in gross final energy consumption was higher than the target rate of the national goal for RES. In Belgium, the Netherlands, and Slovenia, the indicator ranked at a level equal to the goal. The only country to fall short of this goal is France, where a level of just over 19% was achieved against a goal of 23%. Sweden has contributed the most to the EU goal for the share of RES in gross final energy consumption in the community. Assuming a target share of 49%, the country reached a level of over 60%. Furthermore, countries such as Finland, Bulgaria, and Estonia have made significant contributions to the community goal. Considering the share of RES in transport, the European Union also reached its goal (10.2% against 10%). However, there is wide variation at the level of individual countries. Most countries (15 countries) did not meet the goal. Greece (5.3%), Lithuania (5.5%), Croatia, and Poland (6.6% each), as well as Latvia (6.7%), were the furthest away from the goal. Romania also has a low level of RES development in transport, with an indicator of less than 9%. In Sweden, on the other hand, the share of RES in transport has reached nearly 32%, which means a distance from Greece of 6:1. The next countries in the ranking—Finland, the Netherlands, and Luxembourg—are separated from the leader by a significant distance (indicator values are 13.4% and 12.6%, respectively). Transport is responsible for almost a quarter of the EU's greenhouse gas emissions; therefore, a significant reduction in vehicle emissions is a major challenge. These actions, along with the use of intelligent traffic management methods, will result in improved air quality and increased quality of life [1].

When assessing the contribution of the member states to the goal of RES share in gross final energy consumption, it should be noted that achievement of the goal was facilitated by factors such as the COVID-19 pandemic, which resulted in reduced consumption of fossil fuels, e.g., in transport, the use of statistical transfers by the countries, and the national action plans adopted by all member states, which set a path for the development of RES indicating a detailed action plan and measures for achieving the goals. Statistical transfers have been allowed by the directive so that EU countries can secure the implementation of their goal in RES development by transferring energy generated from RES from a country with its surplus.

The use of RES to an increasing extent brings positive effects in terms of environmental pressure and reduction of carbon dioxide emissions into the atmosphere [30,31].

However, the European Union countries are quite different in terms of RES development and the achievement of national goals in this matter [32]. Differences have been present since the beginning of the implementation of RES development priorities in energy production and consumption [33]. As indicated by numerous studies, the share of renewable energy in total energy consumption in the EU countries is steadily increasing, but it depends on various factors in individual countries [34]. At the same time, a high concentration of renewable energy consumption in several countries persists, which accounts for the stability of the European market [35].

The leading source of renewable energy in almost all EU countries was biofuels [36,37]. The use of energy from other sources did not depend on the level of economic development of the country, but on conditions of a natural character, such as topographical and climatic condition [38]. These conditions allow for the use of specific technologies and power plants using, for example, water energy, wind power, or solar energy [35].

However, numerous problems in the use of RES are highlighted, which may provide an important direction for future research. The fundamental problem is to precisely define the place of RES in the strategic vision of energy sector development in a country, together with a thorough analysis of the structure of energy production from renewable sources [3,39–41]. There is also the problem of malfunctioning RES systems, which results in a significant gap between average and maximum power, which does not occur in conventional power plants [36].

6. Conclusions

Classification of countries on the basis of the synthetic indicator indicates that the leaders in RES are Sweden, Finland, and Estonia, while Malta and Poland constitute the group of countries with the lowest level of RES development. Significant variations in the spatial development of RES for EU countries are also highlighted by the fact that a comparable number of countries were included in the group with the highest and high levels of RES potential—11 countries in both analyzed years—while the group with low and lowest levels of RES development included 16 countries.

The search for similarities among the EU countries in the level of RES development using hierarchical clustering showed that the clusters of objects depend to some extent on the place occupied in the ranking of the synthetic indicator of RES development calculated using the Hellwig's method. A significant number of EU countries belong to the same clusters. The strongest grouping is for countries with low levels of RES development. This is most evident in Slovenia, Romania, France, Bulgaria, and Slovakia, which formed a five-element cluster in 2020 and also belonged to the same cluster in 2012, which included four other countries. The resulting clusters of different sizes also show convergence with membership in the four RES development level groups.

The cluster analysis also shows a clear distinctiveness of the RES development ranking leader in the analysis using the taxonomic method. Sweden, as the leader of both analyzed years, forms a separate one-element cluster in 2020, and in 2012 belongs to the least numerous cluster of objects: countries characterized by the highest or high level of RES development. Furthermore, the leaders in level of RES development (the group of countries with the highest level of RES development)—Austria, Finland, Latvia, and Portugal—share similarities, forming a common class of countries in both 2012 and 2020.

The study results can be a valuable source of information for public and EU institutions and individual EU countries to create and implement RES development policy. Economic policy actors can use the results obtained in this way to make decisions on the allocation of public funds, taking into account the current situation regarding the implementation of EU priorities.

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