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Article

Differentiation of the Level of Sustainable Development of Energy Markets in the European Union Countries

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Abstract: The economic development of the EU's countries depends on stable and permanent access to various energy sources. The integration of European energy markets is a long-term process. Each member country has a different energy balance, energy resources and electricity generation technologies. Therefore, comparing Member States with one another is a complex task. The article deals with organizing the set of objects in multidimensional spaces of variables from the point of view of a certain characteristics that cannot be measured in a simple way, i.e., the relative level of the development of energy markets. The following diagnostic variables were adopted for the analysis: consumption of electric energy generated from renewables per capita (TWH/person), hard coal consumption (million tons/person), greenhouse gas emissions per capita, available for final consumption gigawatt-hour per person, final energy consumption thousand tons of oil equivalent (TOE) per person, petroleum available for final consumption (gigawatt-hour), natural gas (terajoule gross calorific value-GCV) per person, energy intensity of GDP (kilograms of oil equivalent (KGOE) per thousand euro, import dependency %. The article draws upon the cluster analysis, which uses the methods and techniques that enable to extract such objects (countries) from the data set, which would be similar to each other and combine them into groups. The purpose of the article is to examine and discus the diversity of Member States on the level of development of energy markets taking into account the specific situation of Poland. The presented model has the potential to be used at the level of enterprises from various industries to evaluate the level of sustainable development. The algorithm modification will only require the selection of available diagnostic variables describing the given enterprise.

Keywords: sustainability; energy markets; cluster analysis

1. Introduction

Sustainable development is one of the many EU priorities. The European Union Treaty declares the actions of all its institutions for the sustainable development of the Member States, which is based primarily on price stability and sustainable economic growth, which allows for full employment and social progress, with particular emphasis on environmental protection. Access to electricity is a condition that determines economic progress and is a factor that directly affects the standard of living of the society [1,2]. Electricity production in European Union countries is diversified due to the available energy sources and the level of development of new technologies. Non-renewable energy sources are still largely used in Member States [3]. Taking action to protect the climate requires action in the field of energy transformation in order to minimize the levels of greenhouse gas emissions and the consumption of non-renewable energy resources [4–6]. Joint actions to reduce emissions are undertaken by EU countries under the adopted Kyoto Protocol [7]. The main objectives of the European Union's energy policy 2050—European Green Deal are focused on environmental objectives that are to lead the Member States to such a level of economic development that will not have a negative impact on the environment, i.e., the so-called environmentally neutral economy [8,9]. Achieving long-term and stable economic development of European countries depends on stable and constant access to various energy sources. Hence, there is a relationship between the development of energy markets and the potential of the Member States to achieve, today and in the future, continuous economic development. Achieving economic growth and development in countries is possible through the implementation of industrial activities in these countries initiatives for sustainable development based on knowledge and innovation, which take into account the highest environmental requirements. Only the implementation of ecological solutions in the industry will bring results at the national level. The concept of corporate social responsibility (CSR) is a practical implementation of the idea of sustainable development in the economy. According to the European Commission, it should be understood as such conducting commercial activity, in which ethical, social and environmental aspects are voluntarily taken into account in relations with the company's stakeholders, i.e., clients, employees, contractors and investors. The expression of conducting business in accordance with the principles consistent with social responsibility is the publication of corporate social responsibility reports in which enterprises disclose both economic as well as social and environmental information. Assistance in creating reliable CSR reports is a series of international initiatives, which include, among others: Global Reporting Initiative (GRI), ISO 26000 and the AA1000 Norm group. Publishing integrated reports in business enables, among others, in a standardized manner the popularization of economic, environmental and social information by enterprises in order to monitor their activity in these areas. Based on integrated reports, it is possible to make comparisons both within individual economic branches as well as inter-industrial comparisons. Measuring progress in achieving sustainable development efforts at both Member State and company level is possible through the publication of integrated corporate social responsibility reports. The issue of measuring the achievements of economies in terms of the set environmental, social or economic goals is a complex task and requires the use of multidimensional analysis methods. Thematic areas can be described by means of a wide variety of diagnostic variables and there is no universal tool that will enable direct comparison of countries or enterprises with each other. The methodology of conducting a comparative analysis of the Member States in terms of the level of development of energy markets presented in the article may constitute an example for practical application both at the level of various enterprises and related economic phenomena. The article presents an algorithm for comparing the level of development of energy markets, which were characterized by nine diagnostic variables such as: consumption of electric energy generated from renewables per capita (TWH/person), hard coal consumption (million tons/person), greenhouse gas emissions per capita, available for final consumption gigawatt-hour per person, final energy consumption thousand tons of oil equivalent (TOE) per person, petroleum available for final consumption (gigawatt-hour), natural gas (terajoule gross calorific value-GCV) per person, energy intensity of GDP (kilograms of oil equivalent (KGOE) per thousand euro, import dependency %. The selection of variables for the study was made based on the analysis of the level of the variability index. The results of the process of standardization of variables and their agglomeration allowed to select groups of countries similar to each other. In relation to the studied variables, as no similar analyzes have been conducted in the literature with this type of variables, research results may constitute an innovative approach to assessing the level of development of energy markets. A comparative analysis was carried out for 2010 and 2018, which allowed for the identification of changes in the energy systems of the Member States. In order to conduct the comparative analysis data from the Eurostat database was used. The methodology presented in the article also enables practical application at the enterprise level and can be a useful tool for monitoring and assessing the progress of enterprises in achieving sustainable development in the field of electricity consumption.

2. Literature Review

Research on the measurement of the level of sustainable development is currently very popular in the literature. However, they cover very different aspects, both environmental, social and economic. Achievement of sustainable development requires an integrated measurement model that takes into account all aspects of countries or a company's sustainability. Environmental sustainability means striving for a balance between a society that can meet its needs in such a way as not to exceed the biological capacity of the surrounding natural environment. The implementation of innovative solutions in the industry in terms of ecological aspects is widely promoted in the European Union countries. An example of such activities is research conducted by the European Commission on the level of eco-innovation and the degree of advancement of eco-innovation implementation [10,11]. The issue of measuring the level of sustainable development is currently widely published in the literature. Assessing the level of sustainable development requires the identification of specific levels of measurement, which in turn means a cascading of the set goals. The designated measurement levels may be global, national or enterprise levels [12]. Due to the wide range of aspects in the assessment of the level of sustainable development concerning social, environmental and economic criteria, the methodologies used in practice are varied and no uniform and universal procedure has been adopted in this regard. An integrated approach to reporting, including standardized criteria and indicators to be achieved at the enterprise level, is becoming a practical approach to solving the problem of measuring the achieved goals in the field of sustainable development [13–15]. Multivariate analysis, on the other hand, provides algorithms and a tool for making mutual comparisons between countries, regions and business sectors in achieving sustainable development goals. As indicated in the introduction, one of the Europe 2020 strategy main priorities in the area of sustainable development is: backing economy that is more resource efficient, more environmentally-friendly and more competitive. Economic growth, which means the process of increasing the production of goods and services, as well as economic development, which leads to an increase in the standard of living of the society, an increase in production as well as an increase in public safety. Economic growth implies an increase in the consumption of natural resources as well as an increase in the consumption of electricity. The sustainable development of European countries relies on stable and permanent access to various sources of energy. The affordable and adequate energy supply plays a crucial role in economic development and progress for each country mainly in the industrial sector [16]. Energy is a major factor to achieve sustainable development goals because energy use is essential for economic, environment and social development [17–19]. Securing the necessary minimum energy supply in each country is a basic condition for the energy security of the state and its citizens [20–23]. Research indicates that further actions are needed to increase energy efficiency by introducing a greater share of renewable energy [24,25] and more effective policies reducing energy consumption by households [26]. In order to evaluate the progress of the European Union countries in achieving sustainable development goals, i.e., the increase in the efficiency of using energy resources in an environmentally friendly manner, comparative studies for 26 Member States of the European Union were conducted in the following article (Malta and Cyprus, due to their negligible share in the production of energy in the EU, were omitted in the analysis). Energy markets in the European Union have been subject to internal integration for years. As the energy market integration is a long-term process, currently the regional energy markets of the Member States still play an important role in the energy system. In 2014, the European Union approved the following climate protection goals: 40% reduction in GHG emissions, at least 32% share of RES sources in the energy balances of a countries, increase in energy efficiency by 32.5%. These three elements in energy sustainability can be identified as a crucial. An increase in energy efficiency is possible from the primary energy, but in technical terms some energy is always wasted when it is converted from one to another or put to use. Developments in the energy efficiency mean that the amount of economic output or satisfaction of human needs per unit of energy can be increased [27]. Many countries showed an increase in the ratio of gross domestic product per unit of energy used [28]. Another way to increase the efficiency of energy use is to control consumption and save it, which will reduce GHG emissions. Renewable energy sources are another solution, the continuous development of which will replace the dependence on fossil fuels [29].

The constantly growing level of greenhouse gas emissions has become the reason justifying the introduction of ambitious climate goals in the European Union to protect the natural environment [30–32]. The European Union member states are countries with a high level of economic development, therefore they have undertaken to implement the decarbonization policy as leading countries in this area on a global scale [33,34]. Fulfilling ecological commitments requires transformation of energy system, which are a multi-year process. The main aim of the article is to analyze the diversity of the energy markets within the member countries and to group similar countries into clusters. The selection of similar countries in terms of the development of energy markets is an innovative approach to research that has not been published in the literature so far. The results of the presented classification can be a useful tool for building a common energy strategy, which is so important in the process of integrating energy markets. In order to select diagnostic variables, an analysis of available indicators of sustainable energy development has been performed. The classification of indicators for the assessment of energy markets was proposed by the International Atomic Energy Agency [35]. Nine variables were selected for analysis based on the available in Eurostat databased. Data for nine diagnostic variables describing twenty-six Member States were collected and organized from the Eurostat database. Based on the data presented in the matrices, the procedure of aggregation and selection into clusters of similar countries in terms of the level of energy market development was carried out. Each member country has a different energy balance and different energy sources conditions and electricity generation technologies. Therefore, comparing Member States with each other is a complex task. The research subject is focused on the multi-dimensional comparative analysis, which was used as a tool enabling comparison of objects described by many variables at the same time.

Polish membership in the European Union requires intensified strategic activities to adapt procedures and regulations, including energy, in line with EU standards. The major directives are as follows: on common rules for the internal market for electricity and amending Directive 2012/27/EU; concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC; concerning integrated pollution prevention and control Directive 2008/1/EC; on the promotion of electricity produced from renewable energy sources in the internal electricity market Directive 2001/77/EC; on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC. The adopted regulations have a significant impact on the process of energy transition in Poland and at the same time constitute a challenge for the Polish mining industry and the energy system.

In the world, the dominant source of greenhouse gas emissions is the energy sector. However, most of the electricity produced worldwide still comes from non-renewable sources such as oil, coal and natural gas. The dynamic development of renewable energy sources has been taking place for many years in the European Union countries, where a number of innovations and huge investments in clean technologies, such as wind and solar energy, have been introduced. However, in the global account where there is a steady long-term increase in energy consumption, it is a low percentage, which means that in the next three decades, with very dynamic growth in Asia, the share of fossil fuels will continue to be high [36].

Total coal consumption will drop by 10%, the share in the structure of primary sources will fall from 18% in 2002 to 13% in 2030. Also the share of nuclear energy will fall significantly, especially in the second forecast period and in 2030 will amount to 7%, which will constitute less than half of this share in 2002. The share of energy production from gas will increase-from the current 23% to 32% in 2030 [35]. Most of the energy produced from renewable sources will be used to produce electricity. The intensity of primary energy consumption will fall by 1.3% per year from 2002 to 2030, mainly due to changes in the structure, i.e., a shift away from energy-intensive production in the EU. Imports of fossil fuels will grow, especially since domestic production will be limited. The Polish economy is currently undergoing a deep energy transformation, which introduces significant restrictions both in the level of fossil fuel extraction as well as the use of fossil fuels for the production of electricity [37]. The structure of the Polish energy balance, which produces 5% of electricity produced throughout the European Union, is significantly different from the structures from the European Union countries due to the highest coal consumption in the energy sector. The Polish energy industry restructuring in Poland has been carried out for many years in order to achieve the assumed ecological goals in the European Union [38–44]. The transformation of the energy market depends on the financial conditions of companies from energy sectors which are currently exposed to high financial risk in Poland [45–49]. The situation of the Polish energy market is unique on the European Union scale, mainly due to the highest share of hard coal and lignite consumption for electricity production [50–52]. The main assumption of transformations in the energy sector of the member states is the increase in the use of renewable sources, which are sources affecting the increase in the degree of energy self-sufficiency [53,54].

The use of renewable sources is increasing significantly and this may be a solution to the problem of growing energy demand [55]. As the cost of renewable energy decreases, its consumption increases, which reduces the use of coal. However, the greater the share of RES (renewable energy sources) in the energy balances, the greater the need to create a level of reserves to secure energy needs in the event of interruption of supplies from renewable sources. Energy storage technologies are still being developed, but the costs are now far from acceptable for industry and households. Therefore, the level of energy security can be most effectively ensured from existing coal power plants that are already available, inexpensive and flexible in Poland [56].

Economic development, which primarily contributes to an increase in the standard of living of the society, is thus a constant increase in the threat to the natural environment. Climate protection is currently a key global problem for both industry and science. The exploitation of energy resources and their burning is associated with the emission of greenhouse gases, the level of which is constantly increasing. The European Union is actively working to stop further increases in emissions [57–62]. The stringent environmental requirements regarding the limits of carbon dioxide emissions in the European Union countries resulted in numerous studies in the field of development and implementation of CO_2 capture and storage technologies (CCS) [63–66].

The literature conducts research on the relationship between economic growth and the level of energy efficiency. In practice, there is a synergistic relationship between energy consumption and economic growth, but each variable causes different mechanisms of positive feedback. The research shows that the effects of reducing the emission level by increasing energy efficiency may be smaller than previously planned. On the one hand, econometric models confirm that increasing energy efficiency contributes little to economic growth and that decoupling is possible and cheap. In turn, the ecological perspective shows that improving energy efficiency is an important contributor to economic growth and decoupling is difficult and costly. In conclusion, the reduction of emissions by increasing energy efficiency may be an insufficient tool in practice, therefore efficient consumption is also proposed [67]. The climate and energy policy in the EU until 2030 aims to develop a low-carbon economy. The goal of transformation is to build an energy system that provides consumers with affordable energy prices, to increase the security of energy supply to the EU, and to reduce the EU's dependence on energy imports. These activities are to bring the intended effects in the form of reduction of greenhouse gas emissions, development of environmentally friendly jobs and green growth [68].

The European Union countries are highly diversified, which means that the pace of structural change and energy transformation will be adequate to the situation [69–74]. The structure of energy resources use is significantly different for selected EU countries, as presented in Figure 1. The biggest energy producer in the EU is Germany, producing 19.68% share of the total of EU. France share in energy production is 17.64% respectively UK 10.62%, Italy 8.77%, Spain 8.74%, Poland 4.99% and Sweden 4.82%. These seven countries produced 75.25% of all energy in the EU.

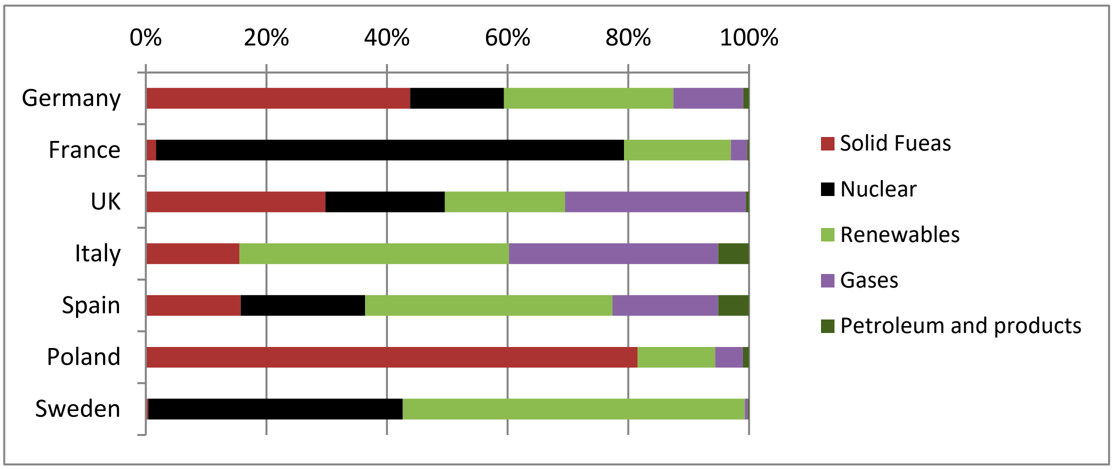

Figure 1. The structure of fuel use in 2016 in selected EU countries (own study).

As presented in Figure 1 the energy structures of selected Member States differ significantly. For a more detailed analysis of the structure of the energy markets of the Member States, nine diagnostic variables were adopted for the analysis, which in-depth describe the differentiation of countries among them.

3. Materials and Methods

The application of the taxonomic measure of energy markets development has been presented in the research as an element of multidimensional comparative analysis. The multidimensional object (characterized by many variables) in this case are the European Union Member States. The algorithm of hierarchical cluster analysis was used. The article presents the application of a multidimensional comparative analysis, as the comparison of European countries whose level of development of energy markets can be characterized using many diagnostic variables is a typical example of this type of analysis. Multivariate comparative analysis is a set of statistical methods that enable the detection of various regularities concerning the examined elements of a given community. Multidimensional comparative analysis is an interdisciplinary method and denotes a scientific discipline dealing with the principles and procedures of classification (ordering, grouping, discrimination or division). The multivariate analysis procedures are applicable wherever there are economic phenomena characterized by a large number of variables, which makes it impossible to use traditional methods.

The main goal of this research is to demonstrate the significant diversity of the European Union Member States in terms of the development of energy markets, which may be an argument for creating an energy policy based on different climate goals for countries depending on the variables characterizing the level of development of energy markets.

Taxonomic analyses generally boil down to two main research tasks. First task is connected with grouping operational taxonomic units and the second task is connected linear ordering relative to the aggregate indicator. The concept of classification is ambiguous and includes both the methodology of segregating a set of objects, the classification process and its final result. The necessity of classification results from the following premises:

- methodological—an analysis that works well to obtain homogeneous subjects, in which it is easier to isolate systematic factors and cause-effect relationships are more pronounced,
- cognitive—based on reducing a large amount of information to several basic categories, which simplifies the process of inference,
- economical—allowing to reduce work input by limiting considerations to typical facts, phenomena, objects with a slight error.

A particularly important issue of classification is the linear arrangement of objects in a multidimensional space of features, consisting in their projection into a straight line.

The taxonomic methods include: cluster analysis; ranking-linear ordering of objects and methods of identification of representatives of classes [75].

The term multivariate comparative analysis refers to a group of statistical methods by which at least two variables describing each object or phenomenon are simultaneously analyzed. These methods are used to study directly immeasurable phenomena that characterize specific subjects analysis. In the presented multivariate analysis, the Member States of the European Union constitute objects, i.e., statistical units subject to grouping. Statistical objects were described using nine diagnostic variables, i.e., features describing the studied population. Based on the collected statistical data from the Eurostat database, it was possible to construct the data matrix presented in Equation (1):

$$X = \begin{bmatrix} X_{11} & X_{12} & \dots\dots\dots & X_{1m} \\ X_{21} & X_{22} & \dots\dots\dots & X_{2m} \\ \vdots & \vdots & \dots\dots\dots & \vdots \\ \vdots & \vdots & \dots\dots\dots & \vdots \\ X_{n1} & X_{n2} & \dots\dots\dots & X_{nm} \end{bmatrix} \quad (1)$$

where: X—object data matrix and X_{ij}—value of the i-th factor in the j-th country where $i = 1, 2, \dots, n$, $j = 1, 2, \dots, m$.

The selection of diagnostic factors used in the analysis was made on the basis of the variability index calculated for each potential variable according to the Equation (2):

$$V_j = \frac{S_j^x}{\overline{x}} \cdot 100\% \quad (2)$$

where:

$$S_j^x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_j - \overline{x_j})^2} \quad (3)$$

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_j \quad (4)$$

Diagnostic factors for which the level of the variation index is above 10% are considered significant in the conducted study. The factors used to describe the objects may be of different nature due to the impact on the general criterion under study. Diagnostic factors can be divided into two categories (stimulants and destimulants) depending on the direction of their influence on the studied phenomenon, sustainable development of energy markets. Stimulants mean factors whose quantitative increase is interpreted as a positive phenomenon, while destimulants are factors whose quantitative decrease is interpreted as a desired phenomenon. The first stage for carrying out a multivariate analysis is the interpretation of the direction of the impact for the nine identified diagnostic factors, the increase of which can be interpreted as positive or negative on the level of sustainable development of energy markets in the Member States. The division of factors into stimulants and destimulants are presented in Table 1.

The collected data for selected diagnostic variables are expressed in different units and dimensions. In order to unify variables into a dimensionless unit, the process of standardization of variables was carried out.

Table 1. Diagnostic variables of sustainable development of energy markets (own study).

		Diagnostic Variable
X_1	Stimulant	Consumption of electric Energy generated from renewables per capita (TWH/person)
X_2	Destimulant	Hard coal consumption (million tons/person)
X_3	Destimulant	Greenhouse gas emissions per capita
X_4	Stimulant	Available for final consumption Gigawatt-hour per person
X_5	Stimulant	Final energy consumption Thousand tons of oil equivalent (TOE) per person
X_6	Destimulant	Petroleum available for final consumption (Gigawatt-hour)
X_7	Stimulant	Natural gas (Terajoule gross calorific value—GCV) per person
X_8	Destimulant	Energy intensity of GDP (Kilograms of oil equivalent (KGOE) per thousand euro
X_9	Destimulant	Import dependency %

Standarized data matrix was calculated according to the Equations (5) and (6) [76]:

Transformation equation for stimulants:

$$z_{ij} = \frac{x_{ij} - \min_i(x_{ij})}{\max_i(x_{ij}) - \min_i(x_{ij})}, \quad (5)$$

Transformation equation for destimulants:

$$z_{ij} = \frac{\max_i(x_{ij}) - x_{ij}}{\max_i(x_{ij}) - \min_i(x_{ij})}, \quad (6)$$

where: X_{ij}—the value of the diagnostic variable (factor) and Z_{ij}—the normalized value of X_{ij} for i = 1, 2, . . . , n, j = 1, 2, . . . , m.

4. Results

The article identifies diagnostic variables for grouping Member States into clusters of countries that are most similar to each other in terms of the level of development of energy markets. The article uses the methods of structural classification called cluster analysis. As a result, several homogeneous subsets were obtained from one heterogeneous set of objects. Those objects that belong to the same set are treated as "similar" and objects in different subsets are treated as "dissimilar" [77].

The purpose of the article is a complex measurement of the sustainable development level of energy markets and a comparative analysis of the European Union countries. Hence for the analysis data for 2010 and 2018 were collected to compare changes of energy markets over a relatively long period of time. The research methodology included a few stages such as:

(1) Defining data matrices,
(2) Division of diagnostic variables into stimulants and destimulants,
(3) Selection of the standarization method,
(4) Developing standardized data matrices,
(5) Analysis of the similarity of the level of development of the energy markets of the Member States based on scatter charts in two-dimensional space,
(6) Construction of dendrograms and grouping of objects into sets of similar elements.

On the basis of the collected data, a selection of significant variables was carried out for analysis, and for this purpose, the variation index was calculated for each potential variable for 2010 and 2018. The results are presented in Tables 2 and 3 respectively.

Table 2. Results of the calculation of the coefficient of variation for potential diagnostic features for a 2010 year (own study).

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
S_j^x	0.00043	0.00050	4.29566	0.00446	0.00253	0.00446	0.03684	94.10411	23.11129
$\overline{x}$	0.00047	0.00052	10.99615	0.00695	0.00300	0.00695	0.04531	199.03923	53.09373
V_j	92.52973	95.46611	39.06510	64.15335	84.11912	64.15335	81.29526	47.27918	43.52922

Table 3. Results of the calculation of the coefficient of variation for potential diagnostic features for a 2018 year (own study).

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
S_j^x	0,000508	0.000405275	3.27555	0.004271	0.002529	0.004271	0.023217	78.96356	21.24434
$\overline{x}$	0.000617	0.000386305	9.4	0.007043	0.002953	0.007043	0.036493	163.5854	53.78688
V_j	82.24271	104.9104374	34.84628	60.6494	85.647	60.6494	63.62067	48.27054	39.49725

Based on the results presented in Tables 2 and 3, nine diagnostic variables were adopted for the analysis, all potential variables have a significant indicator of volatility over 10%. The next stage of the research was the standardization of input data on the basis of Equations (5) and (6). The standardization results are presented in the Tables 4 and 5.

Table 4. The set of variables standardized for a 2010 year (own study).

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9
Belgium	0.071485	0.744432	0.467337	0.317686	0.198097	0.682314	0.390719	0.733688	0.225517
Bulgaria	0.043288	0.810845	0.859296	0.077265	0.006118	0.922735	0.037603	0	0.533296
Czechia	0.100616	0.64455	0.487437	0.174384	0.103309	0.825616	0.16388	0.47018	0.724394
Denmark	0.323578	0.444303	0.537688	0.199456	0.135361	0.800544	0.173337	1	1
Germany	0.15135	0.627465	0.572864	0.253463	0.139406	0.746537	0.220033	0.880125	0.373335
Estonia	0.322518	0.979864	0.59799	0.218928	0.111091	0.781072	0.087464	0.197689	0.744762
Ireland	0.028784	0.817023	0.296482	0.148868	0.100752	0.851132	0.206772	0.990108	0.103215
Greece	0.058178	0.976451	0.628141	0.16185	0.058313	0.83815	0.0408	0.870154	0.310723
Spain	0.117558	0.854236	0.733668	0.184134	0.074575	0.815866	0.148165	0.889264	0.182965
France	0.131089	0.87677	0.758794	0.267192	0.102062	0.732808	0.135114	0.871453	0.480591
Croatia	0.192368	0.889914	0.934673	0.074555	0.041748	0.925445	0.114874	0.679943	0.528178
Italy	0.121052	0.830955	0.728643	0.162437	0.087403	0.837563	0.270007	0.935635	0.17156
Latvia	0.365606	0.960879	1	0.06405	0.092113	0.93595	0.172801	0.514163	0.380432
Lithuania	0.127152	0.982881	0.944724	0.038987	0.034306	0.961013	0.167545	0.57819	0.48699
Luxembourg	0.192115	0.847619	0	1	1	0	1	0.925146	0
Hungary	0.077577	0.922299	0.864322	0.067998	0.048176	0.932002	0.212521	0.527872	0.409528
Netherlands	0.025048	0.66876	0.502513	0.233938	0.17217	0.766062	0.59898	0.819135	0.650695
Austria	0.62575	0.779003	0.708543	0.296733	0.192503	0.703267	0.234487	0.919616	0.331634
Poland	0.039673	0	0.703518	0.054884	0.04561	0.945116	0.043549	0.495028	0.67134
Portugal	0.195288	0.884849	0.81407	0.132145	0.048065	0.867855	0.070005	0.866494	0.164945
Romania	0.094389	1	0.904523	0	0	1	0.094316	0.499935	0.798164
Slovenia	0.248989	0.99975	0.743719	0.188964	0.104994	0.811036	0.069263	0.708841	0.496713
Slovakia	0.0683	0.628196	0.768844	0.135188	0.087378	0.864812	0.213543	0.550071	0.305789
Finland	0.894118	0.401738	0.532663	0.689179	0.286157	0.310821	0.145088	0.715643	0.436819
Sweden	1	0.858727	0.829146	0.640497	0.200793	0.359503	0	0.860106	0.610533
UK	0	0.606895	0.592965	0.173016	0.097848	0.826984	0.328761	0.925354	0.720281

Table 5. The set of variables standardized for a 2018 year (own study).

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9
Belgium	0.073477	0.818203	0.655172	0.308974	0.183934	0.691026	0.624562	0.711078	0.130931
Bulgaria	0.034946	0.933218	0.772414	0.091355	0.013222	0.908645	0.108272	0	0.62102
Czechia	0.093811	0.667823	0.531034	0.186785	0.100008	0.813215	0.254565	0.50272	0.618073
Denmark	0.44337	0.741026	0.772414	0.186105	0.123719	0.813895	0.192177	0.958595	0.759127
Germany	0.146893	0.652417	0.6	0.236727	0.127955	0.763273	0.394611	0.8525	0.334005
Estonia	0.323249	0.979858	0.275862	0.256042	0.110175	0.743958	0.116535	0.229006	1
Ireland	0.037684	0.879123	0.462069	0.165832	0.100926	0.834168	0.365755	1	0.293057
Greece	0.041609	0.98062	0.744828	0.135859	0.031992	0.864141	0.134605	0.77191	0.261024
Spain	0.082464	0.76985	0.848276	0.174915	0.066879	0.825085	0.2397	0.819115	0.231206
France	0.100818	0.894457	0.882759	0.247469	0.089511	0.752531	0.21758	0.825221	0.514119
Croatia	0.129568	0.937355	0.951724	0.071933	0.031838	0.928067	0.189114	0.655409	0.449247
Italy	0.087377	0.874605	0.875862	0.15203	0.067803	0.84797	0.427917	0.873453	0.198696
Latvia	0.415635	0.979898	0.958621	0.06948	0.090755	0.93052	0.250686	0.576289	0.53816
Lithuania	0.12869	0.958211	0.875862	0.063465	0.048507	0.936535	0.211341	0.575651	0.189209
Luxembourg	0.620881	0.892304	0	1	1	0	1	0.901371	0
Hungary	0.012345	0.924952	0.924138	0.085418	0.052585	0.914582	0.325815	0.543736	0.392421
Netherlands	0.010765	0.584313	0.551724	0.237295	0.145097	0.762705	0.813296	0.803297	0.374486
Austria	0.566824	0.783676	0.717241	0.319882	0.187213	0.680118	0.390715	0.865238	0.326691
Poland	0	0	0.62069	0.076314	0.052741	0.923686	0.138678	0.525642	0.532849
Portugal	0.158804	0.775473	0.882759	0.11806	0.035801	0.88194	0.169459	0.777876	0.206487
Romania	0.036027	0.99835	0.972414	0	0	1	0.167704	0.60121	0.75229
Slovenia	0.175561	1	0.793103	0.230623	0.098928	0.769377	0.113525	0.679192	0.464087
Slovakia	0.028342	0.60219	0.827586	0.148161	0.077384	0.851839	0.314328	0.589249	0.33287
Finland	1	0.598431	0.662069	0.694577	0.276217	0.305423	0.136002	0.667952	0.528641
Sweden	0.966442	0.841804	1	0.626136	0.17881	0.373864	0	0.821086	0.700975
UK	0.022657	0.898664	0.848276	0.141788	0.083494	0.858212	0.471233	0.907726	0.631492

The next stage of the research algorithm was an analysis of the similarity of the development level of the energy markets of the Member States based on scatter charts in two-dimensional space Figures 2 and 3.

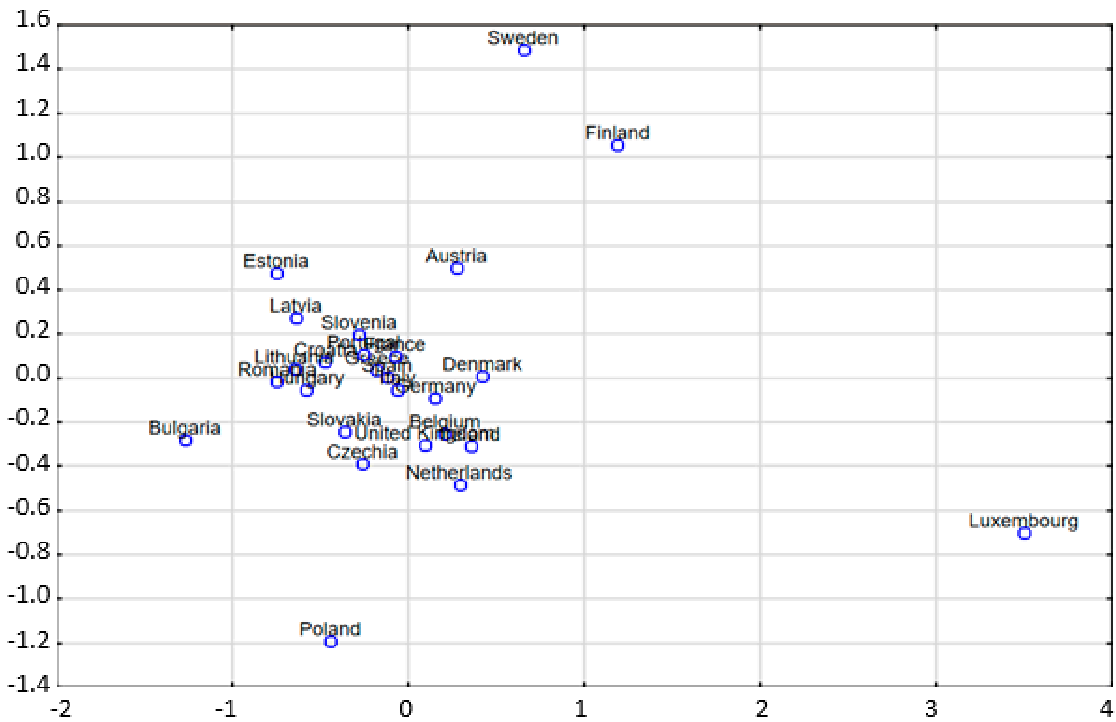

Figure 2. Sustainable development level of energy markets in two-dimensional graph for 2010.

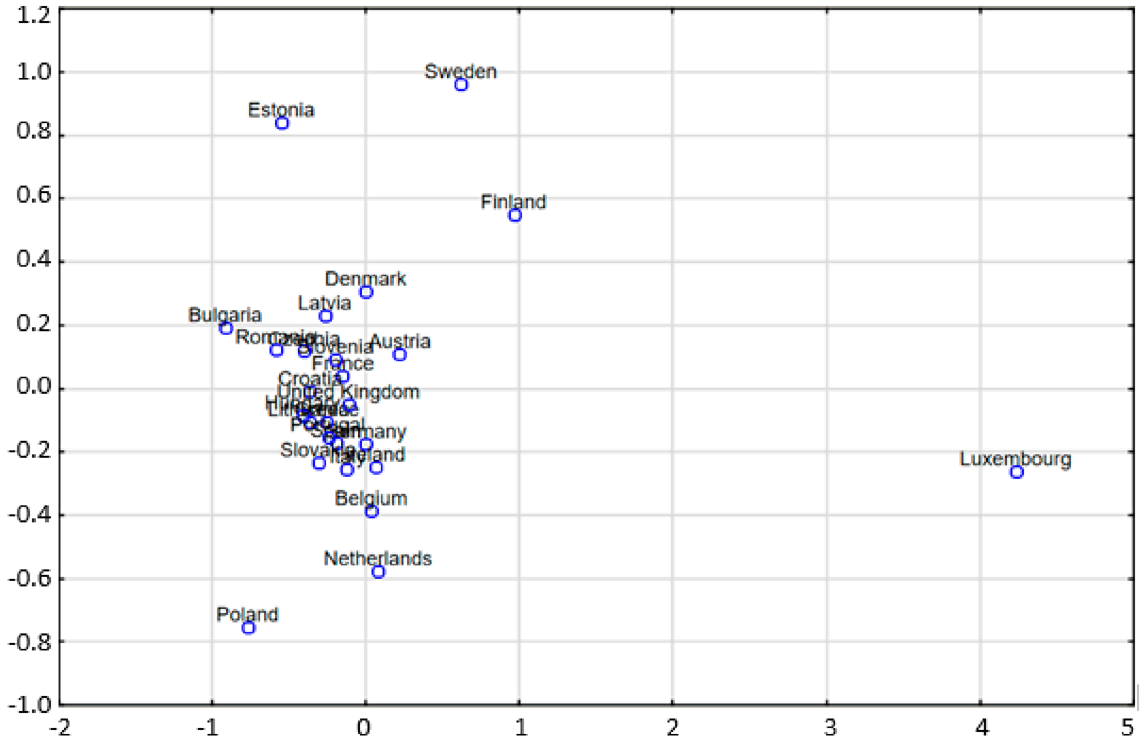

Figure 3. Sustainable development level of energy markets in two-dimensional graph for 2018.

The results of the analysis presented in Figures 2 and 3 show a gradual narrowing of the differences and distances, i.e., distances between individual countries over the analyzed years 2010 and 2018. The changes in distances between countries can be interpreted as structural changes in energy markets, which may be related to the processes of energy transformation and integration of internal markets in the European Union countries. To examine the process of grouping similar countries in terms of the level of development of energy markets comparative analysis was performed using cluster analysis. Cluster analysis techniques include several different algorithms, which can be divided into hierarchical and non-hierarchical methods. The research used the agglomeration method, which belongs to the group of hierarchical methods of cluster analysis. The agglomeration algorithm used for grouping uses the so-called distance or similarity measures. Agglomeration methods are presented in the form of a link tree, i.e., a so-called dendrogram, which is a graphic interpretation of the successive stages of linking objects into clusters. The dendrogram is used to read the connection hierarchy and on this basis enables to determine the relative position of objects. In the agglomeration method, at the beginning, the assumption is made that each object—In the study, the country of the European Union is a separate, single-element group ($G_{r'r} = 1, 2, \ldots, z$). The next step is to connect countries most closely related to each other due to the diagnostic variables described as stimulants and destimulants. Similarity and grouping similar are based on the Euclidean distance between groups of objects. The Euclidean distance is calculated as the square root of the sum of squared differences between the coordinates of a pair of objects:

$$D_{XY} = \sqrt{\sum_{k=1}^{m} (x_{ik} - x_{jk})^2} \quad (7)$$

where: $X = (x_{i1}, x_{i2}, \ldots, x_{im})$, $Y = (x_{j1}, x_{j2}, \ldots, x_{jm})$ are two m-dimensional objects.

In the first step, the distances between single-element groups of objects $G_1, \ldots, G_z$ are elements of the input distance matrix D, in which the algorithm defines the smallest distance between these groups of objects:

$$d_{rr'} = \min_{ii'}\{d_{ii'}\}, \quad i = 1, 2, \ldots, n_r;\ i' = 1, 2, \ \ldots, n_{r'};\ r, r' = 1, 2 \ldots, z;\ r \neq r' \quad (8)$$

where: $d_{rr'}$—distance of the r-th from the r'-th group.

Similar objects are combined into clusters and thus the number of groups is reduced from the initial phase of the algorithm and the construction of the so-called tree of connections begins. Then the distances of the newly created object group are calculated from all other object groups. This process is repeated until all examined objects are finally merged into one cluster. The equation for calculating the distance of the newly created group of objects G_r'''', by combining groups of objects G_r and G_r'', with other groups of objects $Gr''\ ''''$, when creating a connection tree is as follows [76]:

$$d_{r'''r''} = \alpha_r d_{r'''r} + \alpha_{r'} d_{r'''r'} + \beta d_{rr'} + \gamma |d_{r'''r} - d_{r'''r'}| \tag{9}$$

where: $\alpha_r, \alpha_{r'}, \beta, \gamma$—coefficients (parameters) of transformations.

In the elaboration was used the Ward method.

In Ward's method, the distance between two groups of objects cannot be directly represented by the distance between objects belonging to these groups (Figure 4). When creating a connection tree, two groups of objects are combined into one group at any stage, so as to minimize the sum of squared deviations of all objects from these two groups. This means that at each stage of combining groups of objects, these groups are combined into one group, which in effect form a group of objects with the least differentiation due to the variables describing them. The measure of this diversity is the criterion error sum of squares (ESS) presented by the Equation (10):

$$ESS = \sum_{i''=1}^{n_{r''}} d^2_{i''i''c}\left(O_{i''} \in G_{r''},\ O_{i''c} = \overline{O_{r''}} \in G_{r''}\right) \tag{10}$$

where: $d_{i''i''c}$—the distance of i'' object belonging to the newly created r'' group from the center of gravity of this group:

$$O_{i''c} = \overline{O_{r''}} = \frac{1}{n_{r''}} \sum_{i''=1}^{n_{r''}} O_{i''} \tag{11}$$

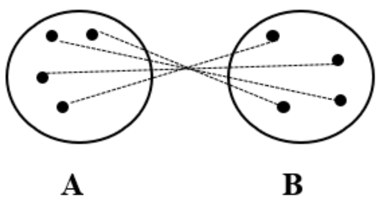

Figure 4. Ward method.

The transformation parameters in Equation (9) have the values:

$$\alpha_r = \frac{n_r + n_{r'''}}{n_r + n_{r'} + n_{r'''}}$$
$$\alpha_{r'} = \frac{n_{r'} + n_{r'''}}{n_r + n_{r'} + n_{r'''}}$$
$$\beta = \frac{-n_{r'''}}{n_r + n_{r'} + n_{r'''}}$$
$$\gamma = 0$$

The results of the agglomerations of countries based on the Ward's method for 2010 and 2018 are presented in the Figures 5 and 6.

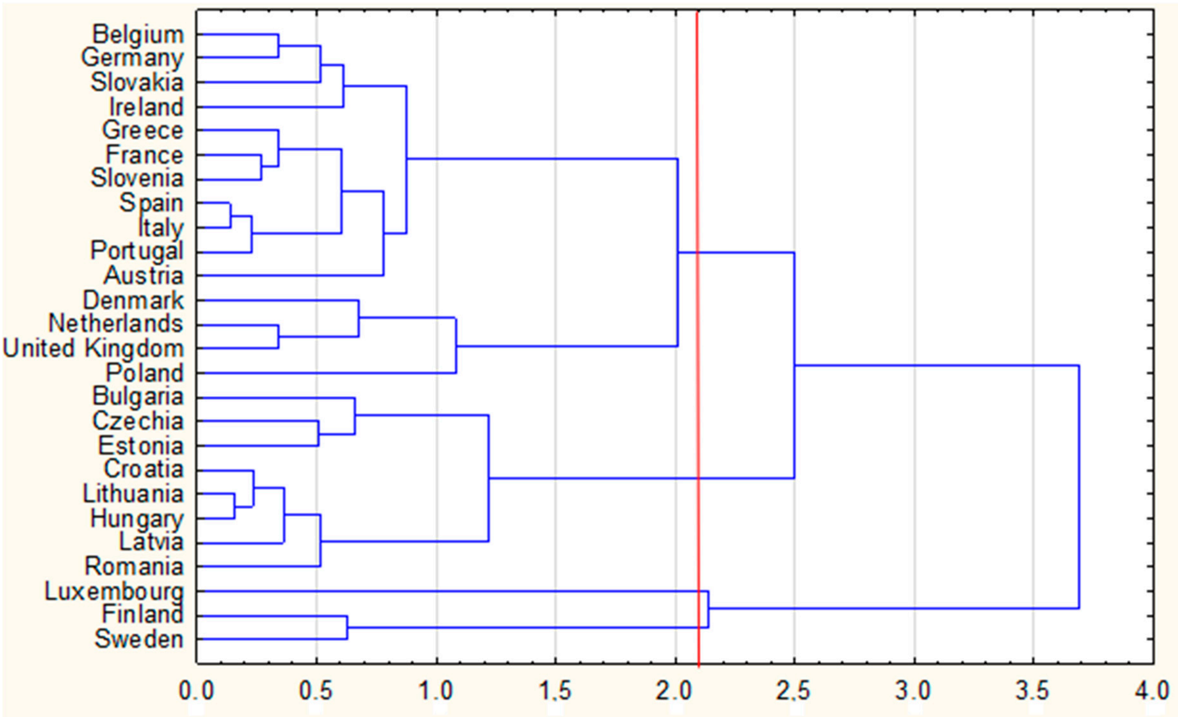

Figure 5. Dendrogram for 2010 using the Ward method.

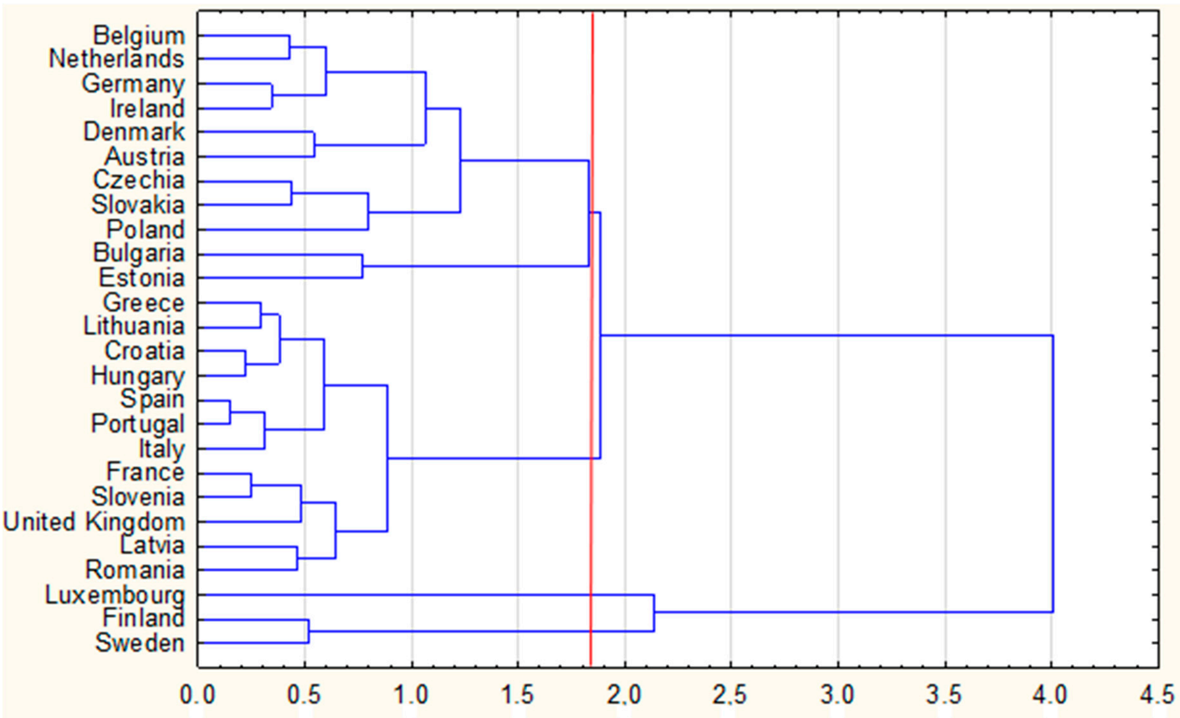

Figure 6. Dendrogram for 2018 using the Ward method.

The agglomeration methods used in the research do not clearly indicate what the optimal number of clusters should be. The substantive interpretation of the obtained results of the agglomeration and the selection of objects depends on the knowledge of the subject matter as well as the experience and intuition of the researcher. The analysis used the interpretation of dendrograms based on the distance. High jump on this chart is synonymous with great distance from each cluster and this point is a place of division. In the Figures 5 and 6 the red lines show places where the division into homogeneous clusters ware made.

The determination of the appropriate number of clusters can be done based on an equation [78]:

$$k \cong \sqrt{\frac{n}{2}} \tag{12}$$

where: k is the number of cluster, n is the number of objects (countries).

Based on the agglomeration shown in Figures 5 and 6 and on the basis of the Equation (12) four groups of similar countries in terms of the level of development of energy markets were identified.

Division into clusters for 2010 by the Ward's method is as follows:

- Cluster I—Sweden, Finland,
- Cluster II—Luxembourg,
- Cluster III—Romania, Latvia, Hungary, Lithuania, Croatia, Estonia, Czechia, Bulgaria, Poland, UK, Netherlands, Denmark,
- Cluster IV—Austria, Portugal, Italy, Spain, Slovenia, France, Greece, Ireland, Slovakia, Germany, Belgium.

Division into clusters for 2018 by the single binding method is as follows:

- Cluster I—Sweden, Finland,
- Cluster II—Luxembourg,
- Cluster III—Romania, Latvia, UK, Slovenia, France, Italy, Portugal, Spain, Hungary, Croatia, Lithuania, Greece,
- Cluster IV—Estonia, Bulgaria, Poland, Slovakia, Czechia, Austria, Denmark, Ireland, Germany, Netherlands, Belgium.

5. Discussion

Analyzing dendrograms charts (Figures 5 and 6) from the left side of the chart, it can be seen that each object—the country is its own class. Moving along the vertical axis of the chart, there is a procedure for assigning two or more countries into the same cluster. An increasing number of objects are linked together and it is possible to aggregate them into new clusters. At the last stage, all objects are connected with each other, which can be seen in the presented dendrograms. The axis level of dendrograms presents agglomeration distances (reverse axis system is also possible). At each node on the chart where a new cluster has formed, there is a possibility of reading the distance at which the relevant elements have been linked together to form a new single cluster. If the data has a distinct "structure" in the sense that there are clusters of similar objects, then often this structure will be reflected on the hierarchical tree in the form of separate branches.

The research results also indicate similarity of countries in terms of geographical location, the conditions of which determine the availability of energy resources and constitute a similar level of development of energy markets. The analysis of the results of the position of countries in the two-dimensional space of the Figures 2 and 3, as well as analysis of dendrograms (Figures 5 and 6) indicate that the most divergent elements in the cluster analysis are Luxembourg and Sweden and Finland, which form clusters 1 and 2, which indicates their significant energy dissimilarity with the Member States concerned. Luxembourg is a single cluster because it is a different object compared to other Member States and has the highest level of electricity consumption per capita and therefore the highest GHG emissions per capita and one of the highest levels of energy dependence. The second cluster has the highest level of energy production from renewable sources on an EU scale. Due to the 9% consumption of solid fuels in the energy mix, Finland has a slightly higher GHG emissions per capita than Sweden and a higher energy intensity ratio. Comparing the grouping of countries carried out in the article for 2010 and 2018, it can be seen that the transformation process of energy systems is a long-term process and the effects of energy transformations that can be observed on the basis of collected statistical data will be very slow.

6. Conclusions

The research presented in the article on the similarity of the level of development of energy markets of the member states broadens knowledge about the structure of energy markets in the European Union. The results of the study enabled the multi-criteria division of EU countries into similar groups, which gives rise to the construction of similar scenarios for the sustainable development of energy markets in these countries. The similarity of energy markets in geographical terms was presented, which should be a key aspect for strategic activities in building the development model of selected groups. It was also important to show the diversity of these countries, which influences the pace of the energy market integration process conducted for many years within the European Union. Based on the agglomeration process carried out for the Member States, which have been described by nine diagnostic variables such as: consumption of electric energy generated from renewables per capita (TWH/person), hard coal consumption (million tons/person), greenhouse gas emissions per capita, available for final consumption gigawatt-hour per person, final energy consumption thousand tons of oil equivalent (TOE) per person, petroleum available for final consumption (gigawatt-hour), natural gas (terajoule gross calorific value-GCV) per person, energy intensity of GDP (kilograms of oil equivalent (KGOE) per thousand euro, import dependency % it is possible to create clusters of similar countries to each other in relation to the examined variables, which describe the level of development of energy markets. As demonstrated in studies, the level of relative development of energy markets in the European Union countries varies considerably. As shown in the charts in two-dimensional space (Figures 2 and 3), there are countries that differ very much from the other countries in terms of nine diagnostic variables characterizing the level of development of energy markets, including Luxembourg, Sweden, Finland, Poland, Bulgaria, Austria, Estonia, Czechia, Belgium and Germany. The agglomeration process was conducted by the Ward's method. The most similar countries have been grouped in four clusters. Luxembourg as a single cluster is the most divergent country from all Member States. Among the nine diagnostic variables tested, it has the highest degree of electricity consumption per capita and therefore the highest GHG emissions per capita. Luxembourg has one of the highest levels of energy dependence, thus, it is an individual object in the cluster. Finland and Sweden have the highest level of energy production from renewable sources on an EU scale. Finland has a slightly higher GHG emissions per capita than Sweden, due to the 9% consumption of solid fuels in the energy mix, and a higher energy intensity ratio. The third cluster in 2010 consists of countries such as: Romania, Latvia, Hungary, Lithuania, Croatia, Estonia, Czechia, Bulgaria, Poland, UK, Netherlands, Denmark. The fourth cluster in 2010 includes the following countries Austria, Portugal, Italy, Spain, Slovenia, France, Greece, Ireland, Slovakia, Germany, Belgium. The third cluster in 2010 brings together countries similar to each other mainly in terms of the level of energy independence, where the average level for the third cluster is 35%, while in the fourth cluster this level was 69%. Another factor determining this division is the energy intensity of GDP (KGOE per thousand euro) parameter for which the average value in the third cluster was 256, which means nearly twice as high as in the countries grouped in the fourth cluster. Another factor distinguishing the countries in the third cluster is greenhouse gas emissions per capita, where the average level was 9.5 and was significantly lower than in the fourth group, where the average level was 11.3. In 2018, there were significant changes to the division of countries into the four collections. The greatest differentiation between the clusters can be observed in relation to the parameter: hard coal consumption (MT/person). Countries grouped in 2018 in the third cluster to which the following countries belong Romania, Latvia, UK, Slovenia, France, Italy, Portugal, Spain, Hungary, Croatia, Lithuania, Greece had a significantly lower average hard coal consumption per person, averaging 0.00017 (MT/person). However, in the fourth cluster, countries such as Estonia, Bulgaria, Poland, Slovakia, Czechia, Austria, Denmark, Ireland, Germany, Netherlands, Belgium hard coal consumption average level was 0.0006 (MT/person). The research presented in the article on the diversification of the level of development of energy markets in European Union countries may constitute an innovative approach to research on the energy transformation taking place in the European Union member states. The results of the analyzes carried out with the use of multivariate analysis show the broad potential of these methods in the study of economic phenomena that can be characterized by many diagnostic variables at the same time.

In the literature, research was conducted on the grouping of European Union countries, inter alia, in terms of the structure of energy production from renewable source [79] and also in terms of the level of production and consumption of electricity [80]. The results of comparative analyzes in the above-mentioned perspectives show different results of grouping countries due to different diagnostic variables adopted for multivariate analysis and different time periods. Access to comparable data for many countries may be difficult in the conducted analyzes, but despite these inconveniences, multivariate analyzes are a useful tool for making comparisons.

The presented research results may be useful in establishing strategic directions of energy transformation taking into account common climate goals and economic integration. Energy policy has a strategic impact on achieving the assumed climate goals, hence the indication of differentiated goals for the identified clusters of similar countries seems to be a project that allows the optimization of activities to achieve the ecological objectives. The research presented in the article shows the complexity of the issue of energy transformation in the countries of the European Union. Studies have shown that the structure of the use of energy resources in the member states varies greatly. The results of the study indicated groups of countries whose level of development of energy sectors is similar. The presented research results may constitute a methodologically important tool for the implementation of emission and ecological standards for the Member States. It is worth noting that the process of transforming the energy structure is a long-term process and changes in the sources and technologies used for energy production depend on the available sources of financing and the availability of energy resources in the European Union, which affects the costs of energy production. The discussion presented in the article on the process of conducting comparative analysis for grouping by multiple criteria at the same time Member States brings an undoubtedly innovative trend in research. The level of diversity of countries in terms of energy markets will undoubtedly affect the pace and extent of changes and systemic transformation. Therefore, it is anticipated that the assumed ecological goals may be achieved by the member countries at different times. The multi-criteria analysis of the diversity of energy markets in the European Union and the impact of energy systems on economic development presented in the article is a current research problem that can be a tool for practical application. The cause-and-effect relations between economic growth, the state of the natural environment and the energy balances of EU Member States presented in the article constitute a current research topic that can be used to design a diversified energy policy, taking into account such important aspects of environmental protection and implementation of solutions to improve energy efficiency. The presented models may be helpful in shaping an environmentally friendly policy by the government, local or commune authorities, and may also be used to popularize active ecological actions in the society.

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