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ASSESSMENT OF THE ELECTRICITY PRODUCTION FROM RENEWABLE ENERGY SOURCES IN SELECTED COUNTRIES OF THE EUROPEAN UNION IN 2010 AND IN 2016 USING MULTIDIMENSIONAL EXPLORATORY TECHNIQUES

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Abstract

The study presents assessment of the production of electricity obtained from renewable sources in selected European Union countries in 2010 and 2016. Among selected countries, the largest amount of electricity from renewable sources in 2010 was produced in Germany – 9,546.56 ktoe and in 2016 – 16,409.73 ktoe. In the analyzed countries of the European Union there was an increase in the production of energy obtained from renewable sources in comparison to 2010 and the dynamics of this growth in selected countries ranged from 106.1% to 217.0%. On the basis of the cluster analysis, it was found that Poland was in a similar group as Hungary in obtaining energy from renewable sources. On the other hand, Austria stood out the most from the surveyed countries, which proves that there is a big difference resulting from the energy management there in the area of obtaining electricity from renewable sources. Based on the principal component analysis, it was found that among selected EU countries, Austria is the most focused on the production of electricity from renewable sources from solid biofuels and water. Germany obtains the largest amounts from the sun, other renewable sources and wind.

Keywords: electricity, renewable sources energy, greenhouse gas emissions, EU, multidimensional exploratory techniques, cluster analysis, principal component analysis

INTRODUCTION

The application of the provisions of Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance), forces the European Union countries to use also renewable sources in energy production.

Depending on climatic conditions and available infrastructure, countries have at their disposal

various renewable energy sources, eg energy from sun, wind, biomass or water.

The European Council requires Member States to achieve a 20% target for the overall share of energy from renewable sources and a 10% target for energy from renewable sources in transport. Each member country has an individual goal that defines the target share of energy from renewable sources. The reason why the European Union has decided to support the use of renewable energy sources in Europe is primarily the security of energy supply. The European Union promotes the use of renewable energy sources, also due to its impact on the reduction of the greenhouse effect (Panwar *et al.*, 2011; Perdiguero and Jiménez, 2011; Solilova and Nerudova, 2015; Barwicki *et al.,* 2017).

Colins *et al.*, (2018) report that in the European Union, the increase in energy production from renewable sources by 2030 can contribute to the reduction of carbon dioxide (CO2) emissions in the energy sector by 43% compared to 2005. Klesmann *et al.*, (2011) states that in order to achieve the planned 20% of energy from renewable sources, Europe must implement an effective policy that will attract sufficient investment. For this purpose, Europe must also modernize its power grid infrastructure. Kitzinga *et al.* (2011) informs that the policy of promoting renewable energy sources can be supported by transferable green certificates, tax reduction and financial support for investments.

The goal of the study was to assess the production volume of electricity from renewable sources in selected European Union countries in 2010 and 2016. Using multidimensional exploratory techniques, an assessment of selected renewable energy sources in selected countries in 2016 was also carried out.

MATERIALS AND METHODS

8 countries from Central Europe were selected for the analysis, and France and Spain were added as one of the largest countries in Western Europe.

Five independent variables (electricity obtained from water, sun, solid biofuels, wind and other renewable sources) were adopted for analysis. To determine the relationship between them, cluster analysis and principal components analysis were used, which are included in multidimensional analyzes. Statistical analysis was developed in the Statistica 13.1 program for data from 2016 obtained from Eurostat.

As a unit of energy, one ton of oil equivalent (toe) was assumed. Where the tonne of oil equivalent (toe) is defined as the amount of energy released by burning one tonne of crude oil and the toe is used for large amounts of energy. Also Eurostat in the energy research methodology assumes that in statistical reporting for European Union countries (used for international comparisons), a *tonne of equivalent oil* is used as energy unit, in fact its multiplicity, eg ktoe (10^3 toe). In this case, typical relationships between individual energy units are as follows: 1 ktoe = 41.868 TJ = 11.63 GWh, 1 GWh = 3.6 TJ = 0.086 ktoe and 1 TJ = 0.02388 ktoe = 0.2778 GWh. The tonne of oil equivalent (toe) is a unit of energy defined as the amount of energy released by burning one tonne of crude oil and the toe is used for large amounts of energy.

Cluster analysis is a set of methods used to extract homogeneous subsets. Clusters have been created by selecting objects located close to each other. As a measure of distance, the most commonly used Euclidean distance was adopted (Stanisz, 2007). To determine the distance between clusters that originated from connected objects, a single-linkage clustering was used, otherwise known as nearest neighbour clustering. The distance between the two clusters is defined here by the distance between the two closest objects belonging to different clusters. The principal component analysis is a statistical procedure which, without significant loss of information, allows to reduce the number of variables and to detect the structure and general regularities in relationships between variables (Stanisz, 2007).

RESULTS

Fig. 1 presents the percentage share of electricity obtained from renewable energy sources in comparison to the total electricity generated from all available sources in a given country in 2010 and 2016.

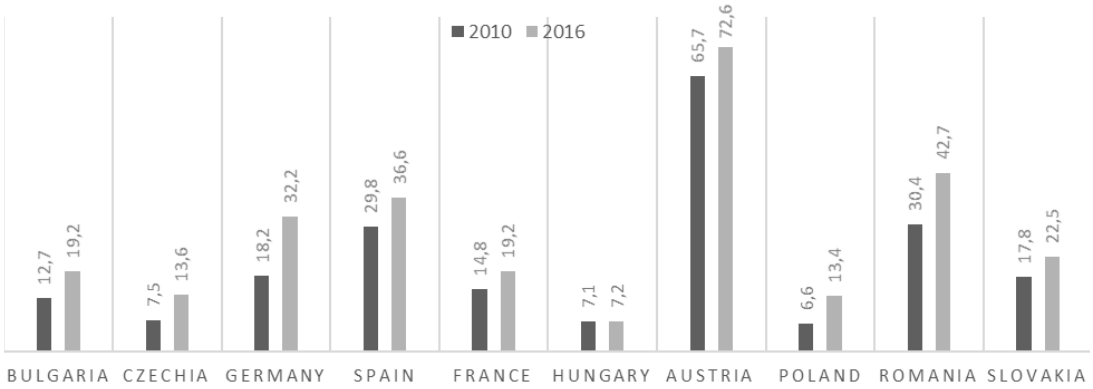
On the basis of Fig. 1, it can be stated that among selected countries, Poland had the smallest percentage share of electricity produced from renewable sources (6.6%), while Austria obtained the result of 64.7%. In 2016, the share of electricity generated from renewable sources in total electricity production increased. However, the largest share was still observed in Austria (72.6%).

Tab. I shows the amount of electricity produced from renewable energy sources in selected European Union countries in 2010 and 2016. The largest amount of energy from renewable sources in 2010 was produced by Germany (9 546.56 ktoe), among the selected countries, Spain also produced a large amount (7 424.98 ktoe). And the least – Hungary

(259.97 ktoe). In 2016, the amount of energy produced from renewable sources was higher in comparison to 2010. The highest dynamics was observed for Poland, the Czech Republic and Germany (respectively: 217.0%, 183.1% and 171.9%), while the smallest growth dynamics occurred in Hungary (106.1%) and Austria (114.0%). The largest total amount of energy produced from renewable sources in 2016 was in Germany (16,409.73 ktoe). In terms of 1 million inhabitants, the smallest amount was produced in Hungary (28.07 ktoe) and in Poland (50.88 ktoe). The largest amounts of electricity from renewable energy per 1 million inhabitants in 2016 were produced in Austria (519.93 ktoe), Germany (199.69 ktoe) and Spain (189.08 ktoe).

The largest amount of electricity from water per 1 million inhabitants is obtained by Austria – 410.38 ktoe, while the least produces Hungary – 2.03 ktoe. In the case of energy obtained from the sun, the highest amount is obtained by Germany (39.86 ktoe) and Spain (25.27 ktoe). Austria produces the most energy from solid biofuels per 1 million inhabitants (36.42 ktoe), while Spain (95.38 ktoe) and Germany (83.75 ktoe) from wind (see Tab. II).

Fig. 2 shows a dendrogram, which presents the hierarchical structure of the set of examined objects. On its basis, it can be concluded that Poland is the closest to Hungary, which indicates a great similarity in obtaining energy in these



1: *Percentage of electric energy obtained from renewable energy sources in comparison to total electricity generated from all available sources in a given country in 2010 and 2016.*
Source: Eurostat. Online data code: nrg_ind_335a, own processing

I: *Production of electricity from renewable energy sources in 2010 and 2016*

Lp.	Country	Code country	Production 2010 (ktoe)	Production 2016 (ktoe)	Dynamics % (2010–100%)	Population 2016	Production per 1 mln inhabitants (ktoe)
1	**2**	**3**	**4**	**5**	**6 = 5/4**	**7**	**8 = 1 mln*5/7**
1	Austria	AT	3 969.10	4 523.66	114.0%	8 700 471	519.93
2	Bulgaria	BG	408.93	633.29	154.9%	7 153 784	88.52
3	Czechia	CZ	454.69	832.74	183.1%	10 553 843	78.90
4	France	FR	6 799.38	8 415.63	123.8%	66 730 453	126.11
5	Germany	DE	9 546.56	16 409.73	171.9%	82 175 684	199.69
6	Hungary	HU	259.97	275.91	106.1%	9 830 485	28.07
7	Poland	PL	890.27	1 931.68	217.0%	37 967 209	50.88
8	Romania	RO	1 523.98	2 188.05	143.6%	19 760 314	110.73
9	Slovakia	SK	435.65	570.43	130.9%	5 426 252	105.12
10	Spain	ES	7 424.98	8 780.97	118.3%	46 440 099	189.08

ktoe - kilotonne of oil equivalent (toe)
Source: Eurostat, online data code: nrg_ind_335a, demo_gind, own calculation and processing

countries from various renewable sources. The Czech Republic acquires more. Slovakia is in a similar group as Bulgaria, France and Romania. However, these countries are located in a greater distance from Germany and Spain, and the largest one from Austria, which indicates a large difference that results from the energy management in these countries in the area of obtaining electricity from renewable sources.

Assessments of similarity between the analyzed countries were also made using the principal components analysis. Electricity produced from water, sun, solid biofuels, wind and other renewable sources was assumed as variables.

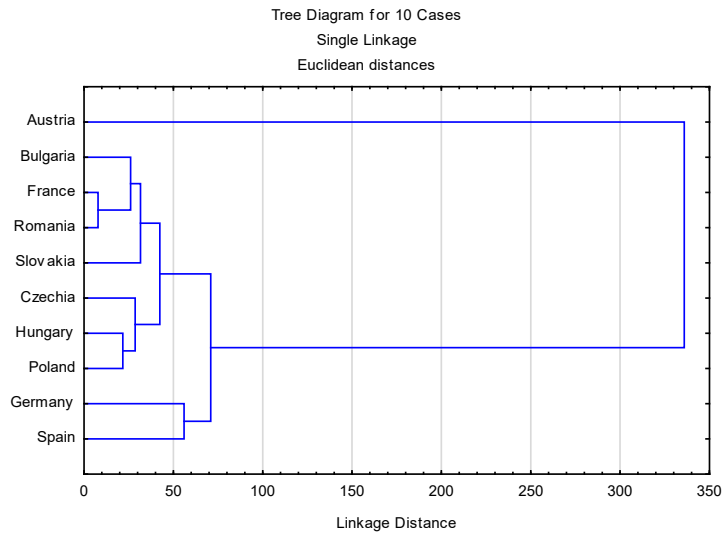
The occurrence of differentiated correlations (see Tab. III) indicated the existence of a structure that had an impact on the principal components. The largest positive correlations can be observed between energy from the sun and other energy sources (r = 0.75) and between energy coming from solid and water biofuels (r = 0.71). The other correlations are low.

II: *Electricity production from renewable energy sources in 2016 in selected European Union countries per 1 million inhabitants*

Lp.	Country	Code	ktoe per 1 mln inhabitants in 2016					
			Hydro	Solar	Solid biofuels	Wind	All other renewables*	Total
1	Austria	AT	410.38	10.83	36.42	53.23	9.07	519.93
2	Bulgaria	BG	50.69	16.66	1.96	16.92	2.29	88.52
3	Czechia	CZ	18.57	17.37	16.85	4.23	21.90	78.90
4	France	FR	76.95	10.51	3.95	28.79	5.91	126.11
5	Germany	DE	22.65	39.86	11.29	83.75	42.13	199.69
6	Hungary	HU	2.03	1.75	13.06	6.17	5.06	28.07
7	Poland	PL	5.32	0.28	15.66	27.27	2.36	50.88
8	Romania	RO	72.62	7.92	2.03	27.88	0.28	110.73
9	Slovakia	SK	69.16	8.45	17.89	0.08	9.54	105.12
10	Spain	ES	57.90	25.27	7.50	95.38	3.04	189.08

*All other renewables means: from gaseous and liquid biofuels, renewable municipal waste, geothermal, and tide, wave and ocean

Source: Eurostat, online data code: nrg_ind_335a, demo_gind, own calculation and processing



2: *Dendrogram created by the single-linkage clustering for obtaining electricity in selected European Union countries from renewable sources per 1 million inhabitants in 2016.*

Source: own processing

Tab. IV presents the eigenvalues of the correlation matrix based on which it can be concluded that the first principal component explains 43.98% of the total variance. The second principal component explains 34.93% of the total variance. Therefore, components 1 and 2 explain 78.91% of the total variance, with the loss of information at 21.09%.

On the basis of Tab. V, it can be assumed that the first two principal components sought are as follows:

Z1 = –0,01H – 0,65S – 0,01SB – 0,53W – 0,55AOR
Z2 = 0,70H – 0,11S + 0,69SB + 0,10W

III: *Matrix of correlation coefficients between the variables*

Variable	Correlations				
	Hydro	Solar	Solid biofuels	Wind	All other renewables
Hydro	1.00	–0.08	0.71	0.21	–0.11
Solar	–0.08	1.00	–0.15	0.70	0.75
Solid biofuels	0.71	–0.15	1.00	0.01	0.18
Wind	0.21	0.70	0.01	1.00	0.32
All other renewables	–0.11	0.75	0.18	0.32	1.00

Source: own processing

IV: *Eigenvalues of correlation matrix*

Value number	Eigenvalues of correlation matrix, and related statistics. Active variables only			
	Eigenvalue	% Total	Cumulative	Cumulative %
1	2.20	43.98	2.20	43.98
2	1.75	34.93	3.95	78.91
3	0.79	15.86	4.74	94.77
4	0.21	4.17	4.95	98.94
5	0.05	1.06	5.00	100.00

Source: own processing

V: *Eigenvectors of correlation matrix*

Variable	Code	Eigenvectors of correlation matrix. Active variables only				
		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Hydro	H	–0.01	0.70	–0.26	–0.61	–0.25
Solar	S	–0.65	–0.11	–0.03	–0.37	0.66
Solid biofuels	SB	–0.01	0.69	0.36	0.49	0.39
Wind	W	–0.53	0.10	–0.63	0.50	–0.25
All other renewables	AOR	–0.55	0.00	0.64	–0.05	–0.54

Source: own processing

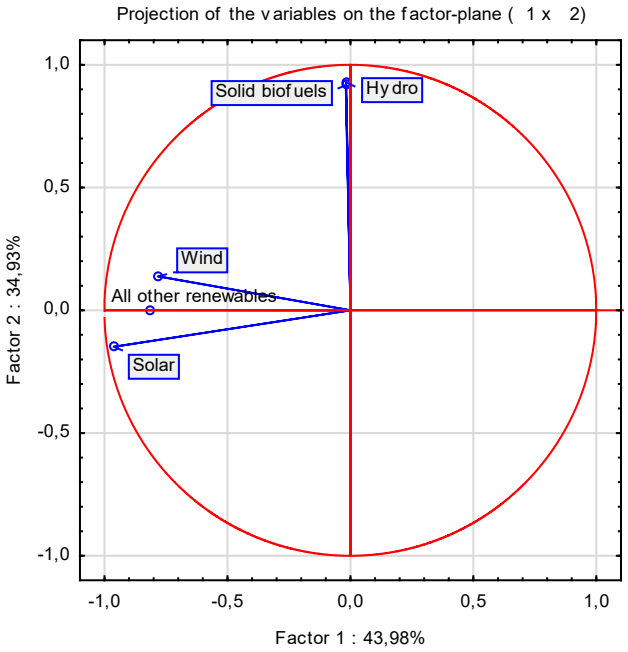
VI: *Factor-variable correlations*

Variable	Factor coordinates of the variables, based on correlations				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Hydro	–0.02	0.93	–0.23	–0.28	–0.06
Solar	–0.96	–0.15	–0.03	–0.17	0.15
Solid biofuels	–0.02	0.92	0.32	0.22	0.09
Wind	–0.78	0.14	–0.56	0.23	–0.06
All other renewables	–0.81	0.00	0.57	–0.02	–0.12

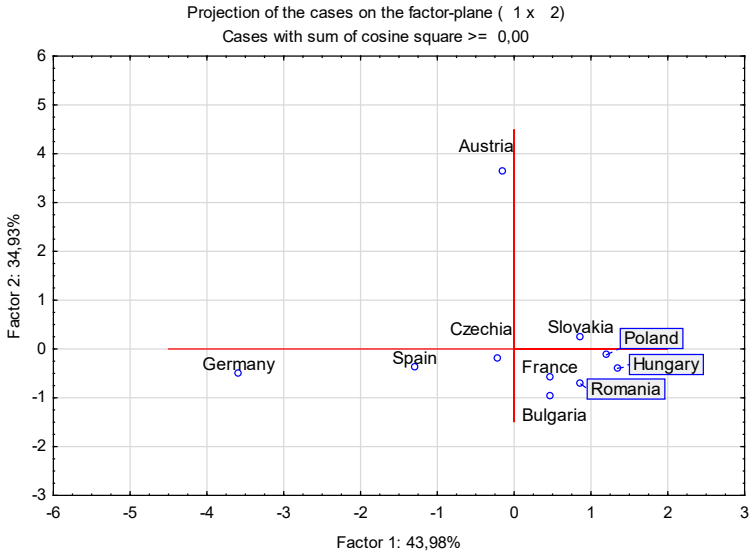
Source: own processing

Tab. VI presents factor-variables describing correlations between variables and components in order to interpret component properties. On this basis, it can be concluded that the first component Z1 and the second component Z2 are the most correlated with the variables due to the fact that they have the highest number of highest factor-variables. For the first component Z1, the highest values of factor-variables were obtained for energy from the sun (–0.96) and other energy sources (–0.81). However, the second component is most strongly affected by energy from solid biofuels (0.92). The next components do not contain a dominant factor-variable and therefore they were excluded from further analysis.

Fig. 3 presents the factor coordinates of variables distribution of five features in the system of selected component pairs. Energy from the sun, wind and other sources is important for the first component of the variable, but it has a negative impact on it.



3: *Plot of variables. Location of load vectors towards two principal components*
Source: own processing



4: *Graph of factor coordinates of cases*
Source: own processing

Electricity obtained from solid biofuels and water has a positive impact on the second component.

Fig. 4 is a graph of factor coordinates of cases. On its basis, it can be stated, taking into consideration the factor-variables, that the location of Austria on the chart shows the largest acquisition of electricity from renewable sources of solid biofuels and water. Germany get the most out of the sun, wind and others. On the other hand, Slovakia, Poland, France, Hungary, Romania and Bulgaria are in the group with indeterminate direction of obtaining energy from renewable sources.

DISCUSSION

The provisions of Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources impose on the European Union member states an obligation to change the structure of energy sources. It is believed that the main source of atmospheric pollution is conventional energy.

The main argument confirming the necessity of using alternative energy sources is the fact that the production of electricity through a renewable source reduces the emission of sulfur dioxide, nitrogen dioxide, carbon dioxide, as well as dusts and slags into the atmosphere.

Involvement of many institutions, for example, in campaigns promoting knowledge about renewable energy, is natural and necessary, while development plans prepared by energy companies to satisfy the current and future demand for gaseous fuels, electricity or heat must take into account the issues of renewable energy.

In the countries selected for the analysis in 2010–2016, an increase in the share of electricity produced from renewable sources was observed. In Poland there was an increase from 6.6% to 13.4%, while in the Czech Republic 7.5% to 13.6%. Among selected European Union countries, Germany produced the most energy from renewable sources, both in 2010 (9 546.56 ktoe) and in 2016 (16 409.73 ktoe).

Due to the diverse population in selected EU countries, the amount of electricity produced from renewable sources per 1 million inhabitants was converted. In Germany, in 2016, 199.69 ktoe of electricity from renewable sources were acquired per 1 million inhabitants, in the Czech Republic 78.90 ktoe, and in Poland 50.88 ktoe. In Hungary, only 28.07 ktoe were obtained. These results indicate a large variation in the amount of electricity obtained from renewable sources per 1 million inhabitants. The reason for this may be the energy policy of a given country. In its assumptions, it determines the share of renewable energy sources in the structure of energy consumption in a given year for the adopted scenario of the economic development of the country after taking into account the potential of renewable energy.

In the examined EU countries, a diversified structure of renewable sources used to produce electricity was observed. Water is the main source of renewable energy in Austria (78.9%). The Czech Republic receives the most from the sun (22%). Hungary (46.5%) and Poland (30.8%) are the leaders in obtaining energy from biomass. Targeting the extraction of renewable energy from specific sources may be caused by economic aspects, access to renewable energy resources (biomass) or geographical conditions (wind strength and the degree of insolation).

Analyzing the problem in a multidimensional approach, that is assuming for each country the acquisition of renewable energy simultaneously from five sources of origin (water, sun, solid biofuels, wind and other sources), the principal components analysis was used. On the basis of this analysis, the following dependencies were found in obtaining electricity from renewable sources: only Austria acquires electricity, mainly from water, Germany is mainly focused on the sun and wind, and Slovakia, Poland, France, Hungary, Romania and Bulgaria are in the group of countries undecided about the direction of obtaining energy from renewable sources.

CONCLUSION

1) In selected countries of the European Union, the largest amount of electricity from renewable sources was produced in Germany (9,546.56 ktoe), similarly in 2016 (16 409.73 ktoe).
2) The highest dynamics of electricity production growth in selected European Union countries in 2016 to 2010 was observed for Poland (217.0%) and the Czech Republic (183.1%).
3) In 2016 among selected EU countries, the largest amount of electricity from water per 1 million inhabitants was produced in Austria – 410.38 ktoe, also in this country the most energy per 1

million inhabitants were obtained from solid biofuels – 36.42 ktoe. From the wind, Spain (95.38 ktoe) and Germany (83.75 ktoe) gained the most energy per 1 million inhabitants.

4) Based on the principal component analysis, it was found that among selected EU countries, Austria is the most focused on the production of electricity from renewable sources of solid biofuels and water. Germany obtains the largest amounts from the sun, other renewable sources and wind. In contrast, Slovakia, Poland, France, Hungary, Romania and Bulgaria are in the group of undecided direction of obtaining energy from renewable sources.

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