Analysis of Similarities Between the European Union Countries in Terms of Sustainable Energy and Climate Development

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INTRODUCTION

Sustainable development is a complex, multidimensional concept, the meaning of which may vary depending on the context and the perspective of a participant in this process (Markovska and Taseska; Tutak et al., 2020; Tutak et al., 2021). Both energy and climate issues are an important component of this process (Brodny and Tutak, 2020, Brodny et al., 2020; Brodny and Tutak, 2019; Im and Kim, 2020) They have become one of the fundamental goals of international policy, as evidenced by their inclusion in Agenda 2030 (United Nations, 2015) among a total of 17 Sustainable Development Goals, the achievement of which is planned for 2030. In terms of sustainable energy and climate development, the agenda includes goal no. 7 – "Affordable and Clean Energy" and no. 13 – "Climate Action".

The implementation of Agenda 2030 goals is taking place in all member states of the United Nations, including the EU countries. This is because the very concept of sustainable development is a fundamental and overarching objective for the European Community, which was included in the Lisbon Treaty (2007). Therefore, both the goals of Agenda 2030 and the EU are convergent in terms of sustainable development, including energy and climate development. This involves concern for the environment, sustainable consumption and production as well as poverty eradication. The issues of climate protection and green energy development play a key role in the sustainable development of the EU. In order to develop a low-carbon economy and increase energy security of the EU countries, a number of strategies have been developed and their specific objectives have been defined. One of the most recent strategies in this area is the European climate strategy called the European Green Deal (2019), which aims to achieve climate neutrality and a "zero-emission" economy by 2050. A key role in this process will be played by the shift from conventional energy sources to renewable, or so-called green, sources.

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Activities related to climate protection and energy transition have been undertaken in the EU for years. Despite this, the EU countries are characterized by considerable diversity in this field. Therefore, it seems reasonable to conduct research on the similarity of the EU countries in terms of sustainable energy and climate development. This will make it possible to fill the research gap in the field of energy and climate condition in the group of these countries. Such analysis will consider not only climatic and energy factors, but also social and economic aspects that can lead to the elimination of energy poverty in society, among other effects.

Therefore, the aim of the research, the results of which are presented in this paper, was to analyze similarities between the EU countries in terms of sustainable energy and climate development. The analysis was carried out for all EU countries, based on 14 indicators characterizing energy and climate sustainability, in energy, climate, social and economic dimensions. Kohonen's artificial neural networks were used for analysis. The research was conducted for data from the period between 2009-2018. The results showed significant differences between the EU countries in the studied period (10 years).

This paper showed a new and original approach to the presented subject due to the wide scope of analysis, the inclusion of many factors from different areas, as well as the research tool used for analysis.

METHODOLOGY OF RESEARCH

In order to conduct a comparative analysis of similarities between the EU countries in terms of sustainable energy and climate development, data from the Eurostat database were used. The time period included in the research was between 2009-2018. The characteristics and values of indicators adopted for analysis are presented in Table 1.

Table 1 Sustainable energy and climate development indicators for EU-27 countries

Dimension	Indicator	Description	Symbol	Stimulant/ Destimulant
Energy	Primary energy consumption, tonnes of oil equivalent per capita	The indicator measures the total energy needs of a country excluding all non-energy use of energy carriers	X1	D
	Final energy consumption, tonnes of oil equivalent per capita	The indicator measures the energy end-use in a country excluding all non-energy use of energy carriers	X2	D
	Final energy consumption in households per capita, kg of oil equivalent	The indicator measures how much electricity and heat every citizen consumes at home excluding energy used for transportation.	X3	D

	Energy productivity, Euro per kilogram of oil equivalent	The indicator refers to the energy consumed by the production unit of GDP	X4	S
	Share of renewable energy in gross final energy consumption, %	This indicator measures how extensive the use of renewable energy is	X5	S
	Energy import dependency by products, % of imports in total gross available energy	The indicator shows the share of total energy needs of a country met by imports from other countries.	X6	D
Social	Population unable to keep home adequately warm by poverty status, % of population	The indicator measures the share of population who are unable to keep home adequately warm.	X7	D
Climate	Greenhouse gas emissions, tonnes per capita	The indicator measures total national emissions of the so called 'Kyoto basket' of greenhouse gases	X8	D
	GHG Intensity of Energy - kg CO_2 eq./toe	The indicator is calculated as the ratio between energy-related GHG emissions and gross inland consumption of energy	X9	D
	Total GHG - GDP Intensity - ton CO_2 eq./M€'15	-This indicator measures ratio between GHG emissions and GDP	X10	D
	Average CO_2 emissions per km from new passenger cars, g CO_2 per km	The indicator is defined as the average carbon dioxide emissions per km by new passenger cars in a given year.	X11	D
Economy	GDP per capita	This indicator is calculated as the ratio of real GDP to the average population of a specific year	X12	S
	Electricity prices by type of user (medium size house), euro per kilowatt-hour	This indicator presents electricity prices charged to final Consumers	X13	D
	Electricity prices by type of user (medium size consumers), euro per kilowatt-hour	This indicator presents electricity prices charged to final medium size consumers	X14	D

Source: Own elaboration based on Eurostat

Kohonen's artificial neural networks were used to determine similarities between the EU countries in terms of sustainable energy and climate development. They are a type of self-learning and self-organizing artificial neural networks. Also, they have several important characteristics that justify their application in data clustering processes. These networks can map complex multidimensional input-output relationships in a low-dimensional space while preserving a topological structure of the original data. They also provide flexibility in grouping data with similar properties (Kohonen, 1990).

Kohonen's neural networks are built with two layers of neurons: an input layer and an output layer (called the competitive layer or Kohonen's layer). The output layer consists of radial neurons, which form a topological map after the network is trained (Muczyński, 2009). All neurons in the input layer are connected to neurons in the output layer by different weights. The initial values of the weights are generated using either random or linear assignment methods. The nodes of neurons in the output layer, which have the same dimension as the input design variables, form a two-dimensional mesh (topological map). In the learning process, the Euclidean distances between the design vector and the weighted vector neuron nodes in the competitive layer are taken as indicators to determine the best match. Once the best match is obtained, the weight value of this match, as well as of neighboring neurons, will be updated to approach the design vector. This training process is repeated until the design vector and the nodes of the neurons in the competitive layer are fully matched (Zhou et al., 2017).

The algorithm used in the Kohonen's method is as follows (Brodny and Tutak, 2020b):

- To determine the size of the topological map (1):

$$k \cong \sqrt{\frac{n}{2}} \quad (1)$$

where:

k – number of neurons (clusters),

n – number of cases (countries).

- To trigger the initial weight vectors.
- To select the learning case (observation).
- To calculate the value of the decision function for all neurons and select the winning neuron.
- To determine neurons adjacent to the winning neuron based on the value of the neighborhood function.
- To adjust the weights of neighboring neurons using the learning rate (adaptation).
- To modify the learning rate and neighborhood size.
- To implement step 2 again if the conditions for completing the learning process of the network have not been met.

A Euclidean measure is used to calculate the distance between input data (*x*) and neuron weights (*w*):

$$d(x, w) = \sqrt{\sum_{i=1}^{k} \left(x_{ij} - w_{ij}\right)^2} \quad (2)$$

RESULTS AND DISCUSSION

Based on 14 indicators of sustainable energy and climate development adopted for the study, an analysis was performed to determine groups of EU countries similar in terms of this development for a 10-year period between 2009-2018. The first analysis involved grouping of the EU countries based on data from 2009. In the first stage, cluster compositions were determined for the 2009 data, which are presented in Table 2 together with the value of the activation function.

Table 2 Elements of clusters and the value of the activation function for 2009

Cluster 1 and value of activation function	Cluster 2 and value of activation function	Cluster 3 and value of activation function	Cluster 4 and value of activation function
Belgium (0.47)	Slovenia (0.64)	Spain (0.53)	Czech Republic (0.43)
Denmark (1.02)	Estonia (0.68)	Croatia (0.73)	Greece (0.46)
Germany (0.44)	Latvia (0.67)	Hungary (0.51)	Cyprus (0.70)
Ireland (0.69)	Lithuania (0.50)	Malta (0.64)	Poland (0.37)
France (0.75)	Romania (0.40)	Portugal (0.74)	Bulgaria (0.90)
Italy (0.72)		Slovakia (0.35)	
Luxembourg (1.29)			
Netherlands (0.38)			
Austria (0.68)			
Finland (0.88)			
Sweden (1.34)			

Countries located inside one cluster are the most similar to one another in terms of energy and climate sustainability, but at the same time, significantly different from countries located in other clusters. In turn, countries in the same cluster show the greatest similarity to one another when located in the central part of the cluster. The further a country is from the center of the cluster, the less similar it is to countries in the center. At the same time, assigning such a country to another cluster would be unjustified because of the lack of similarity to countries in that cluster.

The distribution of countries in the created clusters is shown on the topological map in Figure 1.

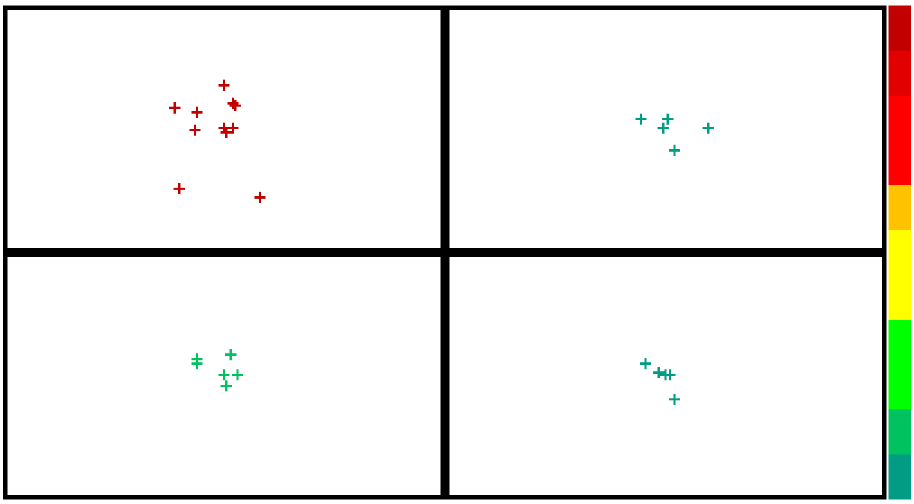

Fig. 1 Distribution of the EU countries in clusters (neurons) on` the topological map in 2009

The analysis of the distribution of the EU countries on the topological map showed that the greatest internal differences were reported for countries in cluster 1 (e.g., Belgium, Sweden, Finland, Germany), and the greatest similarities for countries in cluster 3 (e.g., Spain, Croatia, Hungary) and 4 (e.g., Czech Republic, Poland, Cyprus, Bulgaria).

The results showed that countries with the highest average level of sustainable energy and climate development in 2009 were in cluster 1, and countries with the lowest average level of development – in cluster 4. Cluster 1 included Sweden, Denmark, Austria, and France. These countries should be regarded as leaders in sustainable energy and climate development in the EU. The high position of Sweden, Denmark and Austria results from the fact that their transformation in the energy sector and the gradual transition to renewable energy began as early as the 1970s, which also translated into their climate policy. France, on the other hand, is a country that bases its energy system mainly on nuclear energy, which makes this highly industrialized country combine the goal of economic growth and reduction of greenhouse gas emissions.

Among the countries with the lowest level of sustainable energy and climate development in 2009 was Bulgaria, which is the least wealthy country in the European Community. This country uses energy based on coal and nuclear sources. The total environmental footprint in the form of greenhouse gas emissions in Bulgaria is one of the highest among the EU countries. Bulgaria is also a country with a very high energy poverty rate (more than 64% of the population in 2009).

The basic statistics of the analysis carried out for each cluster are presented in Table 3. In this way specific features of each cluster, formed by a different number of EU countries, were determined.

Table 3 Results of statistical analysis on energy and climate sustainability for each cluster (2009)

Cluster	Indicator	Mean	Median	Standard deviation	Coefficient of variation	Skewness	Kurtosis
1	X1	4.44	3.82	1.67	37.61	1.95	4.16
	X2	3.45	3.13	1.70	49.35	2.56	7.18
	X3	776.64	778.00	137.54	17.71	0.83	0.43
	X4	8.15	7.59	2.05	25.21	0.51	-0.08
	X5	16.61	12.22	14.36	86.48	1.14	0.55
	X6	56.81	61.10	32.26	56.78	-1.29	2.46
	X7	3.64	2.90	3.03	83.20	1.34	2.14
	X8	12.19	11.90	5.08	41.69	2.06	5.68
	X9	1973.03	2075.87	546.13	27.68	-0.48	-0.80
	X10	293.92	303.43	58.36	19.85	-1.31	1.86
	X11	147.32	146.90	9.41	6.38	0.26	-0.53
	X12	37508.18	34040.00	12886.49	34.36	2.69	8.06
	X13	0.19	0.19	0.04	22.22	-0.01	0.47
	X14	0.09	0.10	0.02	23.99	-0.27	-1.64
2	X1	2.39	2.27	0.72	30.24	1.12	2.06
	X2	1.54	1.47	0.44	28.63	0.29	-2.48
	X3	523.60	496.00	196.05	37.44	-0.02	-2.34
	X4	3.15	3.10	0.72	22.74	-0.49	-0.71

	X5	22.24	22.16	8.02	36.04	0.54	1.77
	X6	39.83	45.39	16.96	42.58	-0.15	-2.05
	X7	25.70	22.10	23.24	90.43	1.41	2.87
	X8	7.70	6.40	2.83	36.74	1.72	3.03
	X9	2230.66	2518.61	651.30	29.20	-0.45	-2.03
	X10	893.31	891.78	336.49	37.67	0.87	0.77
	X11	168.46	170.30	7.50	4.45	-0.85	0.89
	X12	7804.00	8500.00	2264.67	29.02	-0.15	-1.27
	X13	0.09	0.10	0.01	8.83	-0.40	1.11
	X14	0.08	0.08	0.02	19.65	-0.36	-2.68
3	X1	2.40	2.31	0.32	13.23	0.74	-0.99
	X2	1.67	1.71	0.31	18.48	-1.64	3.38
	X3	407.67	371.50	184.62	45.29	0.12	-1.19
	X4	5.03	4.32	1.85	36.79	0.73	-1.46
	X5	13.71	12.33	9.14	66.68	-0.14	-0.62
	X6	72.04	73.65	19.12	26.55	0.09	-0.39
	X7	11.27	8.60	8.79	78.06	2.01	4.52
	X8	7.48	7.45	0.83	11.03	0.08	-1.98
	X9	2180.00	2134.35	345.43	15.85	1.80	
	X10	530.68	539.40	141.28	26.62	-0.09	3.84
	X11	139.80	138.95	9.50	6.79	0.18	-0.75
	X12	14425.00	13505.00	5047.16	34.99	1.05	0.76
	X13	0.15	0.15	0.02	12.44	-1.41	3.16
	X14	0.12	0.12	0.03	22.46	0.10	-1.75
4	X1	3.12	3.33	0.61	19.52	-0.27	-1.78
	X2	2.12	2.37	0.37	17.41	-0.84	-1.98
	X3	535.00	524.00	95.99	17.94	0.14	-3.00
	X4	5.17	5.08	1.59	30.83	0.33	-1.91
	X5	10.80	8.73	5.71	52.87	1.85	3.84
	X6	54.29	49.07	28.26	52.06	0.81	-0.35
	X7	12.70	15.70	7.50	59.03	-0.15	-2.35
	X8	11.60	11.50	1.65	14.23	-0.07	-2.45
	X9	2874.46	2716.34	484.33	16.85	0.23	-2.32
	X10	732.43	560.85	263.99	36.04	0.87	-1.73
	X11	155.44	155.50	3.81	2.45	0.42	-1.26
	X12	16952.00	17760.00	5945.91	35.07	-0.71	-0.36
	X13	0.13	0.13	0.02	14.00	0.06	-2.28
	X14	0,10	0,10	0,01	11,53	0,30	0,03

The next stage of the analysis involved grouping the EU countries by similarity in terms of their energy and climate sustainability based on the 2018 data. The created clusters are presented in Table 4, and the distribution of countries on the topological map for each cluster is shown in Figure 2.

Table 4 Elements of clusters and the value of the activation function for 2018

Cluster 1 and value of activation function	Cluster 2 and value of activation function	Cluster 3 and value of activation function	Cluster 4 and value of activation function
Belgium (0.62)	Slovenia (0.61)	Greece (0.69)	Czech Republic (0.29)
Denmark (0.82)	Croatia (0.54)	Spain (0.42)	Estonia (0.75)
Germany (0.68)	Latvia (0.57)	Italy (0.47)	Poland (0.56)
Ireland (1.42)	Lithuania (0.48)	Cyprus (0.74)	Bulgaria (0.95)
France (0.74)	Hungary (0.47)	Malta (0.87)	
Luxembourg (3.23)	Romania (0.67)	Portugal (0.57)	
Netherlands (0.78)	Slovakia (0.64)		
Austria (0.46)			
Finland (1.51)			
Sweden (0.99)			

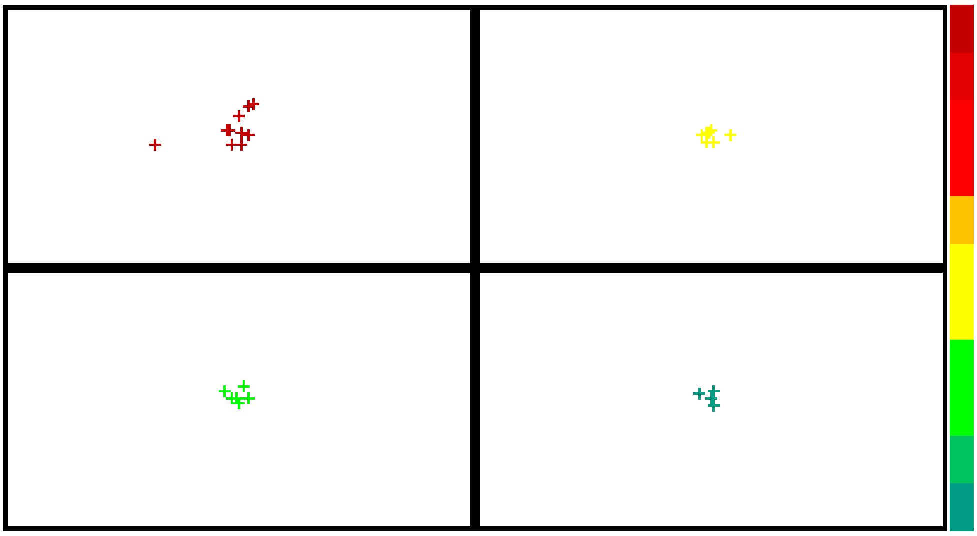

Fig. 2 Distribution of the EU countries in clusters (neurons) on the topological map in 2018

Table 5 summarizes the basic statistics on the conducted analysis for individual clusters.

Table 5 Results of statistical analysis on energy and climate sustainability for each cluster (2018)

Cluster	Indicator	Mean	Median	Standard deviation	Coefficient of variation	Skewness	Kurtosis
1	X1	4.26	3.68	1.38	32.53	1.56	1.86
	X2	3.41	3.03	1.48	43.38	2.17	4.91
	X3	721.00	721.50	142.93	19.82	1.01	1.44
	X4	10.13	9.01	3.97	39.20	1.33	1.57
	X5	23.48	16.56	16.51	70.33	0.80	-0.66
	X6	57.67	61.63	22.20	38.50	0.04	-0.41
	X7	3.02	2.50	1.35	44.80	0.78	-1.07
	X8	10.77	10.70	4.04	37.55	1.38	3.30
	X9	1693.13	1726.64	538.72	31.82	-0.36	-0.40
	X10	221.12	218.64	53.11	24.02	-0.79	0.51
	X11	118.23	118.00	8.48	7.17	0.18	-0.91
	X12	51110.00	44260.00	18864.37	36.91	2.14	4.75
	X13	0.22	0.19	0.06	26.88	0.69	-1.39
	X14	0.08	0.08	0.02	23.32	2.14	5.72
2	X1	2.34	2.43	0.41	17.40	-0.48	0.03
	X2	1.77	1.90	0.35	19.95	-0.66	-0.96
	X3	489.00	533.00	123.16	25.19	-0.27	-1.84
	X4	4.60	4.84	1.02	22.26	-1.99	4.86
	X5	23.10	23.88	9.64	41.74	0.62	0.60
	X6	50.52	52.70	16.95	33.56	-0.24	-0.51
	X7	13.90	7.70	11.76	84.59	1.25	-0.37
	X8	6.94	6.60	0.96	13.76	0.48	-1.79
	X9	1844.86	1719.46	289.19	15.68	0.71	-1.05
	X10	605.31	499.28	249.08	41.15	2.43	6.05
	X11	125.54	127.70	5.08	4.05	-1.58	1.67
	X12	13272.86	13910.00	3125.57	23.55	-0.80	-0.37
	X13	0.13	0.13	0.02	17.43	0.10	-1.47
	X14	0.09	0.09	0.00	4.09	0.56	-0.50
3	X1	2.34	2.32	0.44	18.81	-0.14	-0.36
	X2	1.74	1.75	0.29	16.83	0.06	-1.27
	X3	347.00	343.00	113.33	32.66	0.49	1.08
	X4	7.33	7.43	2.20	29.93	-1.00	2.40

	X5	17.56	17.61	7.29	41.51	0.85	2.24
	X6	81.04	75.98	11.24	13.87	0.93	-1.29
	X7	15.80	16.75	6.52	41.29	-0.28	-2.24
	X8	7.93	7.40	1.99	25.12	0.90	1.11
	X9	2209.92	2105.20	374.76	16.96	0.93	0.02
	X10	359.16	334.35	120.48	33.54	0.46	-1.71
	X11	113.35	113.35	6.92	6.11	0.27	-1.32
	X12	23695.00	25200.00	4540.69	19.16	-0.62	-0.42
	X13	0.19	0.20	0.04	20.88	-0.67	-0.17
	X14	0.10	0.09	0.02	21.70	0.77	-1.76
4	X1	3.59	3.51	0.86	23.94	0.45	-0.42
	X2	2.23	2.31	0.24	10.59	-1.51	1.98
	X3	599.25	588.50	103.88	17.33	0.19	-4.90
	X4	4.43	4.39	1.19	26.81	0.21	1.42
	X5	19.38	18.03	8.07	41.65	0.80	-0.21
	X6	33.40	40.77	22.57	67.58	-1.60	2.65
	X7	3.35	3.00	1.24	36.92	1.38	1.84
	X8	11.75	11.60	2.82	24.04	0.30	0.68
	X9	2573.48	2508.77	522.10	20.29	0.43	-2.84
	X10	701.30	774.21	211.92	30.22	-1.39	1.37
	X11	126.72	126.70	4.78	3.77	0.03	0.48
	X12	18650.00	19755.00	3955.86	21.21	-1.50	2.81
	X13	0.15	0.15	0.01	8.56	-0.12	-4.41
	X14	0.08	0.08	0.01	9.38	-1.84	3.38

Source: Own elaboration

The results showed that countries with the highest average level of sustainable energy and climate development in 2018 were found in cluster 1, and countries with the lowest average level of this development – in cluster 4. It was found that cluster compositions changed insignificantly versus 2009. Italy, which in 2009 was in cluster 1, in 2018, was the most similar to countries from cluster 3. Croatia and Slovakia were found to be in cluster 2 (in 2009, they were in cluster 3). Greece, on the other hand, was in cluster 4 in 2009, and in 2018, it was in cluster 3. Estonia, which showed similarity to countries in cluster 2 in 2009, was reported to have the greatest similarity to countries in cluster 4 in 2018.

Changes that occurred in the composition of individual clusters indicate the progress or its lack in the pursuit of sustainable energy and climate development of individual countries. In general, only Croatia, Slovakia and Greece slightly improved their energy and climate development over the 10-year period (apart from the leading countries in cluster 1, which maintained a high level of development the whole time).

CONCLUSION

The paper presents the results of similarity analysis of the EU countries in terms of sustainable energy and climate development for 2009-2018. The analysis was conducted using 14 indicators of energy and climate development, focusing on the priority areas of the EU in terms of the latest concept of the European Green Deal and Goals 7 and 13 of the 2030 Agenda for Sustainable Development. The analysis was performed in energy, environmental, economic, and social dimensions, using Kohonen's artificial neural networks (the so-called self-organizing maps).

The created clusters of similar countries showed their high differentiation. At the same time, this division made it possible to assess changes in the studied area over a period of 10 years and indicate countries to which special assistance should be addressed, aimed both at substantive and financial support in energy and climate transformation. Such measures should be directed at undertaking more intensive actions in the scope of energy sector modernization and reduction of greenhouse gas emissions. Countries that require special attention in this area include Bulgaria, Poland, Estonia, and the Czech Republic. The situation of these countries in the studied 10-year period did not improve in relation to other EU countries.

The method applied and the results obtained provide great opportunities for a broader analysis in the field of sustainable climate and energy development of the EU countries, also in terms of the impact of examined areas on this development.

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Abstract: Energy and climate issues are an essential part of the sustainable development process of the EU countries. They are also one of the primary objectives of international policy, as evidenced by their inclusion in Agenda 2030, adopted by the UN in 2015 among the Sustainable Development Goals. The implementation of these goals is also taking place in the EU countries. Although climate protection and energy transition activities have been undertaken in the EU for years, individual countries significantly vary in this regard. The aim of the research, the results of which are presented in this paper, was to analyze similarities between the EU countries in terms of sustainable energy and climate development. The analysis was conducted for all EU countries, based on 14 indicators characterizing energy and climate sustainability, in energy, climate, social and economic dimensions. Kohonen's artificial neural networks were used for analysis. The research was conducted for data from the period between 2009-2018. The results showed that in the studied period (10 years), significant differences were found between the EU countries. A high level of energy and climate development was reported for Sweden, Denmark, Austria and France, among other states, and a low level for e.g., the Czech Republic, Poland and Bulgaria.

Keywords: sustainable energy and climate development, similarity analysis, EU countries, artificial neural networks