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The analysis of similarities between the European Union countries in terms of the level and structure of the emissions of selected gases and air pollutants into the atmosphere

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ABSTRACT

Based on the newly adopted strategy "The European Green Deal", by 2050, the European Union should become the first climate neutral region worldwide. This very ambitious goal will require many political, social and economic activities. Huge financial resources will also be needed to change the economy in order to reduce the emissions of harmful substances into the environment. The implementation of such an ambitious climate policy requires the development of a very reasonable economic plan, backed by many analyses, to ensure adequate financing of this idea. One of the basic objectives of such a plan should be to appropriately target aid funds to a group of countries with a similar structure of the emissions in question. The identification of the groups of similar countries in terms of the structure of harmful substance emissions requires the development of both appropriate methodology and applicable studies. Such methodology is presented in this paper, namely the Kohonen's artificial neural network model. The main objective of the developed methodology was to divide the European Union countries into groups similar in terms of the emissions of selected gases and dusts into the atmosphere. In addition to the division of the European Union countries into similar groups by the total volume of the emissions of studied substances, completely new division criteria were introduced. It was assumed that in order for the results of this study to be practically used, it is necessary to broaden the scope of the analysis. Therefore, an additional division of the European Union countries was made in relation to the volume of the emissions per capita, the value of gross domestic product and the area of a given country. This new approach was intended to show the diversity of the European Union countries in economic, demographic and geographical terms. The grouping results should be regarded as additional information to be utilized when preparing specific action plans to improve the state of the environment. Definitely, these plans need to be dedicated both to the groups of countries and the entire sectors in these groups. This will enable the efficient use of financial resources and can be a huge impetus for the European Union economic development. It will also allow smaller and less prosperous countries to achieve their goals. Undoubtedly, the developed methodology and conducted research allowed the authors to solve a significant research problem, and the results can be successfully used in practice.

1. Introduction

1.1. Preliminaries, objectives and outline of the study

The European Union (EU) countries have been undertaking intensive actions for many years to reduce greenhouse gas and air pollutant emissions into the atmosphere (The European Commission, 2015, 2018; 2019; The European Parliament and the Council of the European Union, 2001, 2003; 2009, 2010; 2018). These activities are based on a comprehensive approach that combines economic, social and environmental issues in a way that ensures their mutual reinforcement in accordance with the idea of sustainable development (WCED, 1987). Due to the complexity of this problem and the fact that it applies to virtually all areas of life, policymaking also has an impact on decisions made. Therefore, the subject of environmental protection requires a very objective and

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relatively comprehensive approach (Böhringer et al., 2009; Corradini et al., 2018; Peña and Rodríguez, 2019).

The issues related to the limitation of greenhouse gas and air pollutant emissions have been addressed since the end of the 20th century. A protocol on greenhouse gas emissions was adopted in 1997 in Kyoto and entered into force on February 16th, 2005 (UNFCCC, 2008). According to this document, greenhouse gases include carbon dioxide, methane, freons, steam, nitrous oxide, ozone, halon, and some other industrial gases (e.g. HFC, PFC, and SF_6). In order to fulfil the obligations arising out of the Kyoto Protocol (UNFCCC, 2008), the EU developed a measurement system for greenhouse gas emissions. Moreover, they introduced an emission trading system, as well as clean development mechanisms and joint implementations. In 2015 in Paris, 195 countries signed an agreement, the key provision of which was to keep the average global temperatures well below 2 °C above pre-industrial levels and to pursue the efforts to reduce temperature increase to 1.5°. In order to prevent dangerous climate change, in October 2014, the Heads of State and Government of the Member States of the European Union adopted new objectives concerning both climate and energy through 2030. They include the reduction of EU greenhouse gas emissions by at least 40% by 2030, compared to 1990 levels. The achievement of this objective would represent the European Union's contribution to the provisions of the Paris climate agreement (The European Commission, 2015).

With regard to limiting air pollutant emissions more generally, the representatives of the European Union (EU) Member States approved new air pollution limits for the EU countries in 2016, including limits on sulfur dioxide, particulate matter and nitrogen oxides. This served as the basis for amending the directive on national emission ceilings (Directive, 2016). The provisions of this directive contain the countries' commitments to limit the emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), ammonia (NH_3), and fine particulates (with a diameter of less than 2.5 μm). The new commitments are supposed to halve the number of deaths caused by poor air quality by 2030. By this time, emission limits for harmful compounds are supposed to be lower than those established for the years 2020–2029.

Actions taken to reduce greenhouse gas and air pollutant emissions have resulted in a notable change, though smaller than expected. Within nearly a decade, the emission of carbon dioxide into the atmosphere has been reduced by nearly 20%, while the emissions of methane and nitrous oxide have been reduced by approximately 14% (Eurostat, 2017). The best results for air pollution emission reductions were more broadly achieved for sulfur oxides (emissions reduced by approximately 66%) and non-methane volatile organic compounds (emissions reduced by approximately 24%) (Eurostat, 2017) (Fig. 1).

Moreover, the EU has taken further actions to decrease greenhouse gas and air pollutant emissions. In 2018, the European Commission presented a long-term economic strategy till 2050 (The European Commission, 2018). According to this strategy, the economy of the EU Member States should become neutral both for the climate and the environment. At the same time, however, it is to provide favorable conditions for economic development and for a modern and competitive economy. A year later, in December 2019 at the COP25 Climate Summit in Madrid (Spain) (COP25 Summary Report, 2019), the European Commission presented another plan - the European climate strategy called the European Green Deal (The European Commission, 2019). As agreed in this strategy, by 2050, the EU should become a "zero-emission" economy, i.e. climate neutral, and by 2030 carbon dioxide (CO_2) emissions should be reduced by 50% (plans include even a 55% decrease) versus the emission of this gas in 1990. These assumptions are more ambitious than those adopted at the COP24 Climate Summit, which took place in December 2018 in Katowice (Poland) (COP24 Summary Report, 2018). The European Green Deal plan includes a number of actions aimed at stopping climate change and reducing the level of pollution emitted into the atmosphere. The goal of these activities for the EU is to become climate neutral as the first region in the world. This process is expected to be achieved while maintaining the balance of nature and sustainable development of the economy, as well as improving the health and quality of life of its citizens.

In order to combat climate change and environmental degradation through the emission of greenhouse gases and air pollutants into the atmosphere, all EU countries must undertake a joint venture. This, however, may lead to certain problems. The reason is the large diversity of the EU countries in economic, social, organizational and geographical (location, area size, etc.) sense. All these factors mean that running one common policy can be really difficult, especially when considering the accomplishment of these objectives.

It is obvious that in order to achieve climate neutrality, many countries will need to introduce changes to the economic, social and organizational structure. Also, in many cases, it will cause disturbance to the established social order and traditions related to, for example, the employment arrangement. In order for these changes to be accepted by individual EU countries, it is necessary to develop clear and, if possible, fair economic programs that will support the entire transition process.

In order for the developed programs to take into account the diversity of the EU countries, it is essential to obtain a range of information about the specificity of these countries. Since the purpose of the introduced changes is to limit the emission of harmful substances into the environment, it is evident that the knowledge of the current state of this emission should be expanded. The analysis of the absolute values of substances emitted by individual countries is a valuable source of information yet does not fully show the specificity of individual countries. This data seems to be too general to take proper actions by introducing economic changes to reduce the emissions in question.

For this reason, the authors decided to consider additional criteria when studying harmful gas and dust emissions into the atmosphere. These criteria include comparing the volume of emissions to the number of inhabitants of a given country, the value of gross domestic product (GDP) and surface area. These additional factors (demographic, economic and geographical) should show the diversity of the EU countries and signal the diversity of problems that may occur in these countries when introducing climate change.

The above-mentioned approach will undoubtedly point to significant differences between the EU countries, but it will not solve the problem of reducing emissions of harmful substances into the environment. In order to support the decision-making process and broaden the knowledge of potential economic assistance to individual countries, it was proposed to divide the EU countries into groups with similar characteristics related to the examined factors. It is clear that with the large fragmentation of the EU countries and with various levels of economic development, a uniform climate policy may be hard to follow.

This policy, especially in the field of financial assistance, should be dedicated to groups of countries with a similar level of economic development as well as demographic and geographical potential. Such grouping can have a very positive impact on many areas of life in these countries and can help obtain the social acceptability of the introduced changes.

Unfortunately, with regard to the presented research problem, namely the division of the EU countries into similar groups by taking into account the factors in question, no scientific studies can be found. In other words, a research gap has been created which, for the effectiveness of the EU climate policy, should be filled as soon as possible. In order to solve this problem, the authors decided to work on research methodology that would allow a credible division of the EU countries into homogenous groups based on the adopted criteria.

Eventually, this research methodology was developed based on the artificial neural network model that enabled the achievement of the research objective. This objective was to group the EU countries into homogenous groups by the total amount of gas and dust emissions, their quantity per capita compared to the value of GDP and area of individual countries.

At the same time, the results will make it possible to answer the question whether taking these factors into account will affect the composition of designated similar groups of countries. This is an immensely crucial question as the answer may indicate the direction of the common EU policy, especially in the area of pro-ecological activities for groups of similar countries, such as the so-called Just Transition Mechanism.

Of the many methods that can be used for this type of analysis, the Kohonen's artificial neural networks were selected for this study. They are utilized for exploratory data analysis, including the identification of homogeneous objects characterized by many variables (here: greenhouse gases and air pollutants). This method allows the isolation of possible causal relationships between studied objects. In this study, these objects included the EU countries. The structure and volume of greenhouse gas and air pollutant emissions in these countries were characterized by nine variables. The substances accepted for the analysis included three greenhouse gases (carbon dioxide, methane, nitrous oxide) and six other air pollutants (ammonia, non-methane volatile methane compounds, and sulfur oxide, PM2.5 and PM10).

Undeniably, both the methodology and the results constitute a new approach to analyzing the emissions of harmful substances in the EU countries. Also, they are an example of applying scientific methods to solve a research problem, the results of which can be successfully applied in practice. Not only does it involve the common climate policy addressed to groups of countries, but it also means direct cooperation between countries in given groups. In this regard, this cooperation, including joint investments, exchange of experience and a similar social policy, should be an additional value of the analysis. It should also result in cooperation at the scientific, economic and organizational levels.

This, in turn, may also have very positive managerial implications. Dedicating European funds to a group of countries for specific business projects related to environmental protection should stimulate the economy and provide an incentive to switch from, e.g. conventional energy sources to alternative ones. This should lead to the development of renewable energy and the use of ecological energy sources in transport, communication, heating of apartments, and many other areas of life.

To sum up, it can be stated that the paper presents a new approach to the analysis of harmful emissions into the environment, taking into account the diversity of the EU countries. The developed methodology based on the artificial neural network model enabled a clear division of the EU countries into homogenous groups, considering completely new grouping criteria, and thus is a valuable scientific achievement of this study. Previous studies in this area looked at this topic in a very general and difficult to quantify manner. However, this paper presents very specific results, which, according to the authors, also have a great practical value.

It is therefore reasonable to state that demographic, economic and geographical factors considered in the study allowed for a completely new approach to the analysis of gas and dust emissions into the atmosphere. In addition, the division of the EU countries into similar groups, including the factors in question, should be regarded as a completely new perspective to this subject. It is also important to use the Kohonen's neural networks, which undoubtedly increase the reliability of the results. The developed methodology based on this model also significantly increases the scientific value of the study. It can be assumed that the presented work is an example of the effective application of scientific methods to analyze phenomena related to environmental protection.

1.2. Brief literature review

The issue of greenhouse gas and air pollutant emissions by the EU countries is an important research problem in the field of environmental (Ramanathan and Feng, 2009; Winiwarter and Klimont, 2011; Cárdenas et al., 2018), medical (Campbell-Lendrum and Corvalán, 2007), social (Hatzopoulou et al., 2011; Kan et al., 2012), economic (Ramphull and Surroop, 2017), and political (Bollen and Brink, 2014; Mardones and Cabello, 2019) sciences.

In this complex, multidimensional structure created by the EU, it is necessary to make comparisons between the countries based on various criteria that help to identify both similarities and differences between them.

In fact, the essence of the EU is to unify all areas of life, obviously over time. Nevertheless, at the current level, it is very difficult to achieve, especially in the area of climate policy. However, the superiority of this problem means that it is important to look for a way to achieve environmental improvement.

It seems that cooperation between similar countries and the implementation of joint assistance programs in such groups are most likely to be successful. For this reason, the literature review focused only on issues related to the comprehensive approach to the problem of environmental protection in the EU countries and other groups of countries.

In the current literature, which is related to the comparative analyses of the EU countries, the most common focus was on comparing countries in terms of selected factors. Part of this work concerned analyses related to the comparison of greenhouse gas emissions from selected sectors of the economy. In work (Konstantinaviciute and Bobinaite, 2015), the authors compared carbon dioxide emissions from the energy sector in the EU countries. In other studies, the authors presented the analyses of gas emissions from agriculture (Dace and Blumberga, 2016; Pérez Domínguez et al., 2009), mining (Camarero et al., 2014; Fugiel et al., 2017) and maritime transport in the EU (Aksoyoglu et al., 2016; Russo et al., 2018).

Earlier analyses looked at the changes in the intensity of greenhouse gas emissions in selected EU countries (Bhattacharyya and Matsumura, 2010; Marrero, 2010; Meirong et al., 2012; Su et al., 2016), and also compared countries in terms of the changes in the relative uncertainty of greenhouse gas emissions from stationary sources (Lesiv et al., 2014). Comparative analyses also focused on trading systems of greenhouse gas emissions from European agriculture (De Cara and Jayet, 2011; Robaina-Alves and Moutinho, 2014).

The comparative analyses of the selected EU Member States also examined the impact of energy consumption from renewable and non-renewable energy sources on carbon dioxide emissions (Shafiei and Salim, 2014), and the impact of implementing electric mobility on greenhouse gas production in Central European countries (Skrúcaný et al., 2019). Also, they looked at the relationship between economic complexity, energy consumption structure and greenhouse gas emissions (Neagu and Teodoru, 2019), the impact of economic growth and energy consumption on greenhouse gas emissions (Sterpu et al., 2018), as well as similarities between the EU countries in terms of air pollution (Guerreiro et al., 2014; Lapinskienė et al., 2014). The subject of the presented studies, and many others, mainly aimed at analyzing the absolute values of harmful substance emissions and, in a few cases, also at comparing these emissions.

Therefore, there is no comprehensive approach to the emission of harmful gases and dust in the context of the diversity of the EU countries. Available studies failed to cover the main concept, which was taken into account by the authors of this paper, namely the division of the EU countries into similar groups based on different criteria. A comprehensive analysis of the structure of gas and dust emissions is of great importance due to the practical possibility of reducing these emissions, better cooperation between similar countries and better management of aid funding. Therefore, such an analysis seems fully justified. Considering the wealth of individual countries, their demographic potential and area size also provides a new look at the topic in question. None of the presented works concerned a simultaneous comparison of the EU countries with a large number of variables characterizing a given country in terms of the emissions of various substances into the atmosphere.

Moreover, with regard to the tools adopted in these studies, it should be noted that statistical methods and analytical models were most frequently used. No wider use of more advanced methods was reported, which in the case of analyzing the similarity of countries characterized by many variables seems to be a must. Thus, the Kohonen's neural networks were applied in this study.

To date, the Kohonen's neural networks have not been used to analyze similarities between countries in terms of the volume or structure of greenhouse gas and air pollutant emissions into the atmosphere.

In the context of the literature query, it should be stated that so far, no comparative analysis of the similarities between the EU countries in terms of the volume or structure of both greenhouse gas and air pollutant emissions into the atmosphere has been carried out. All current studies have focused on the main greenhouse gas emissions - carbon dioxide or total greenhouse gas emissions. In the case of air pollution, the research gap in the area of the similarities between the EU countries is even greater since the focus has been only on dust emissions.

Thus, it can be assumed that the conducted research and the results presented in the paper allowed the authors to fill this gap and enabled the acquisition of new knowledge in the field of the emissions of harmful substances into the environment. This perspective also indicates the need for a new approach to testing emissions of harmful substances. In order to acquire new knowledge, it is necessary to consider more factors, and thus more advanced scientific methods. In this respect, the use of artificial neural networks is fully justified.

With regard to the foregoing, it should be stated that the approach presented in the paper is both new and original, and the results significantly broaden the knowledge of this issue and provide new information on individual EU countries. This, in turn, creates opportunities to target pro-ecological activities to specific groups of similar countries, including the Just Transition Mechanism.

2. Methods and materials

2.1. Materials

In order to perform a comparative analysis of the similarities between the EU countries in terms of the volume of main greenhouse gas and air pollutant emissions, data form the Eurostat database from 2017 was utilized. The comparative analysis was conducted for nine selected substances emitted into the atmosphere by 28 EU countries.

The data shown in Table 1 was used in the study. It included the emissions of carbon dioxide, methane, nitrous oxide, ammonia, non-methane volatile organic compounds, PM2.5 and PM10 pollutants, and sulfur oxide reported in 2017.

The emission values of studied gases and air pollutants (Table 1) were compared to the GDP value of a given country (Appnedix 1), their number of inhabitants (Appendix 2) and surface area.

The Kyoto Protocol, as an international environmental agreement adopted by the parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 to counteract global warming and limit the emissions of gases that contribute to the greenhouse effect, encompasses seven greenhouse gases divided into two groups, namely non-fluoride gases and fluoride gases (EEA, 2018a; UNFCCC, 2008). The present analysis encompassed only non-fluoride gases. These gases include: carbon dioxide, methane and nitrous oxide, The data concerning the total emissions of these gases into the atmosphere by the EU countries were obtained for the following sectors: energy, industrial processes and product use, agriculture, waste management and other.

In terms of air pollutant emissions, the comparative analysis involved six main air pollutants in the EU countries: CO, PM10, PM2.5, NO_x, NH_3, SO_x. In total, the comparative analysis included nine substances emitted into the atmosphere (three main greenhouse gases - CO_2, CH_4, N_2O and six air pollutants - CO, PM10, PM2.5, NOx, NH_3 SO_x).

The data concerning the total emissions of pollutants into the atmosphere is derived from 9 sectors, namely energy production and distribution, energy use in industry, road transport, non-road transport, agriculture, commercial institutional and households, industrial processes and product use, waste, and other sources (EEA, 2018b).

Variables that determine the volume of greenhouse gas and air pollutant emissions into the atmosphere were initially statistically analyzed and their basic statistical parameters were determined. They are listed in Tables 2–5, respectively.

Based on the results, it can be concluded that the substances selected for the analysis meet the condition of diagnostic features. This means that they need to be marked with comparability, different degree of correlation and, above all, significant variation, i.e. greater than 10% as determined by the coefficient of variation (Hellwig, 1968).

For the studied substances, the values of the coefficients of variation are characterized by a wide range. The highest coefficient of variation was reported for SO_x emissions in total and in relation to GDP (146.61% and 140.76%). The smallest value of the coefficient of variation was found for NMVOC emissions in relation to the number of inhabitants and amounted to 24.97%.

2.2. Kohonen's neural network

The Kohonen's artificial neural network was applied to determine similarities between individual EU countries in terms of greenhouse gas and air pollutant emissions according to the criteria presented earlier. The Kohonen's neural network is a type of artificial neural network without a teacher (the so-called self-organizing map). It does not have any previous information about the existence of the cluster in the data set during the learning process. This network consists of a self-organizing system capable of displaying multi-dimensional data over a small-sized space, especially in a two-dimensional space, which facilitates the interpretation of the data set without losing the original information (Balbinot et al., 2005; Garcia et al., 2007; Silva et al., 2008; Zupan and

Table 1
Structure of greenhouse gas and air pollutant emissions into the atmosphere by the EU countries in 2017.

	CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SOx	NOx
	thousand tonnes								
Belgium	102 366.53	318.92	19.92	66 749	109 104	23 088	33 408	37 573	176 273
Bulgaria	48 114	271.39	17.94	49 440	77 232	31 967	47 030	103 071	102 813
Czech Republic	106 680.92	540.43	19.59	67 003	207 340	39 940	51 280	109 962	163 205
Denmark	37 700.47	275.38	18.29	76 333	102 258	20 061	31 058	10 254	111 954
Germany	827 082.49	2 209.86	126.4	673 251	1 068 758	99 056	205 986	315 477	1 187 502
Estonia	18 833.81	42.84	3.07	10 255	22 245	9 222	13 911	38 653	33 200
Ireland	41 764.18	561.37	22.65	118 496	113 349	11 970	27 281	13 221	110 307
Greece	78 279.35	396.59	14.6	55 209	148 098	25 814	56 505	105 844	249 536
Spain	291 353.35	1 600.54	61.33	518 192	617 768	105 098	172 098	220 443	738 890
France	363 707.13	2 250.22	140.91	606 358	611 960	164 487	254 230	143 782	807 225
Croatia	19 165.83	164.33	5.7	37 642	63 241	16 726	25 378	12 557	54 852
Italy	360 157.58	1 754.09	59.72	384 192	935 000	164 677	195 690	115 171	709 070
Cyprus	8 536.82	34.56	0.98	6 488	12 321	1 290	2 054	16 391	14 543
Latvia	7 660.94	72.19	6.78	16 519	38 100	17 973	25 009	3 996	37 421
Lithuania	13 724.6	130.29	10.18	29 547	45 727	9 081	14 196	13 177	53 437
Luxembourg	10 925.92	23.75	1.07	5 805	12 101	1 345	2 005	1 011	18 314
Hungary	50 341.26	301.55	15.73	87 700	141 520	47 988	68 866	27 722	119 283
Malta	2 036.24	7.5	0.15	1 113	2 815	238	378	151	5 343
Netherlands	176 492.66	721.22	29.27	132 119	252 074	14 004	26 928	26 898	251 905
Austria	72 224.81	263.89	11.76	69 095	120 189	15 613	27 942	12 809	144 712
Poland	339 052.68	1 976.51	69.88	307 522	690 737	147 281	246 310	582 656	803 661
Portugal	58 493.39	379.08	10.44	57 606	167 536	51 268	72 805	47 520	159 009
Romania	76 003.92	1 149.02	26.29	164 336	240 088	111 925	143 200	106 932	231 717
Slovenia	14 333.1	84.07	2.35	18 634	29 808	11 480	12 986	4 878	34 711
Slovak Republic	36 198.66	184.05	6.47	26 545	89 478	18 068	22 587	27 037	65 665
Finland	46 802.32	184.24	15.73	31 083	88 323	17 800	29 179	35 020	129 850
Sweden	44 803.23	180.73	16.34	53 336	146 939	20 098	40 302	17 566	124 025
United Kingdom	419 518.49	2 058.26	64.2	283 147	809 420	106 814	170 786	172 877	893 108

Table 2
Basic statistical parameters of studied variables from 2017 for all the EU countries.

Variable	Mean	Median	Minimum	Maximum	Standard deviation	Coefficient of variation, %	Skewness	Kurtosis
	thousand tonnes							
CO_2	131155.5	62138.69	2036.24	827082.49	185462.07	138.86	2.37	6.48
CH_4	647.7	326.07	7.5	2250.22	752.81	114.12	1.24	−0.03
N_2O	28.5	18.59	0.15	140.91	35.69	123.02	2.09	4.11
NH_3	141.2	64.728	1.11	673.25	188.14	130.84	1.82	2.34
NMVOC	248.7	154.79	2.82	1068.76	304.87	120.38	1.58	1.30
PM2.5	46.6	30.12	0.24	164.68	51.49	108.54	1.30	0.37
PM10	72.1	45.31	0.38	254.23	78.63	107.05	1.26	0.20
SO_x	83.0	75.07	0.15	582.66	123.85	146.61	2.85	9.63
NO_x	269.0	200.51	5.34	1187.50	328.17	119.80	1.55	1.21

Table 3
Basic statistical parameters of studied variables from 2017 for the EU countries per capita.

Variable	Mean	Median	Minimum	Maximum	Standard deviation	Coefficient of variation, %	Skewness	Kurtosis
	thousand tonnes							
CO_2	7.5×10^{-3}	6.7×10^{-3}	3.5×10^{-3}	1.8×10^{-2}	3.3×10^{-3}	43.70	1.82	4.22
CH_4	4.0×10^{-5}	3.5×10^{-5}	1.8×10^{-5}	1.1×10^{-4}	1.7×10^{-5}	44.04	3.12	13.27
N_2O	1.8×10^{-6}	1.6×10^{-6}	3.6×10^{-7}	4.5×10^{-6}	1.0×10^{-6}	54.40	1.17	1.10
NH_3	8.0×10^{-6}	7.8×10^{-6}	3.0×10^{-6}	2.0×10^{-5}	4.0×10^{-6}	49.91	2.62	9.99
NMVOC	1.5×10^{-5}	1.5×10^{-5}	7.0×10^{-6}	2.0×10^{-5}	4.0×10^{-6}	27.17	−0.03	−0.07
PM2.5	3.3×10^{-6}	2.9×10^{-6}	1.0×10^{-6}	1.0×10^{-5}	2.0×10^{-6}	60.89	1.25	2.01
PM10	5.0×10^{-6}	4.9×10^{-6}	7.0×10^{-6}	1.0×10^{-5}	3.0×10^{-6}	60.57	1.23	2.43
SO_x	5.7×10^{-6}	3.1×10^{-6}	3.6×10^{-7}	3.0×10^{-5}	6.0×10^{-6}	105.72	2.63	8.26
NO_x	1.7×10^{-6}	1.5×10^{-5}	1.1×10^{-5}	3.0×10^{-5}	5.0×10^{-6}	30.06	1.17	0.98

Gasteiger,1991, 1999).

The Kohonen's neural network is composed of a single neural layer with a two-dimensional arrangement. The general scheme of the Kohonen's neural network (Fig. 2) may be represented by columns within a frame, containing — as the weight levels — the number of input vector elements (x), which correspond to the values of the variables of the data for a given sample. In this paper, the (x) vector corresponds to the values of the variables for each object. All the neurons contain a specific number of weights (w), which is the same for each neuron, according to the dimensions of the input vectors (x) (i.e., the number of variables in the analysis). In other words, each neuron may be represented by a vector of d-

Table 4
Basic statistical parameters of studied variables from 2017 for the EU countries in relation to the GDP value.

Variable	Mean	Median	Minimum	Maximum	Standard deviation	Coefficient of variation. %	Skewness	Kurtosis
	thousand tonnes							
CO_2	0.34	0.27	0.09	0.93	0.21	61.00	1.50	2.02
CH_4	1.9×10^{-3}	1.8×10^{-3}	4.0×10^{-4}	6.1×10^{-3}	1.4×10^{-3}	74.32	1.41	1.88
N_2O	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-5}	4.0×10^{-4}	1.0×10^{-4}	86.39	1.91	3.76
NH_3	4.0×10^{-4}	3.0×10^{-4}	1.0×10^{-4}	1.0×10^{-3}	3.0×10^{-4}	65.39	0.89	−0.23
NMVOC	7.0×10^{-4}	6.0×10^{-4}	2.0×10^{-4}	1.5×10^{-3}	4.0×10^{-4}	60.08	0.49	−1.25
PM2.5	2.0×10^{-4}	1.0×10^{-4}	2.0×10^{-5}	7.0×10^{-4}	2.0×10^{-4}	99.48	1.25	0.67
PM10	3.0×10^{-4}	1.0×10^{-4}	3.0×10^{-5}	9.0×10^{-4}	3.0×10^{-4}	94.46	1.19	0.47
SO_x	4.0×10^{-4}	2.0×10^{-4}	1.0×10^{-5}	2.0×10^{-3}	5.0×10^{-4}	140.76	2.17	4.34
NO_x	8.0×10^{-4}	7.0×10^{-4}	3.0×10^{-4}	2.0×10^{-3}	5.0×10^{-4}	60.40	0.91	−0.06

Table 5
Basic statistical parameters of studied variables from 2017 for the EU countries in relation to the area.

Variable	Mean	Median	Minimum	Maximum	Standard deviation	Coefficient of variation %	Skewness	Kurtosis
	thousand tonnes							
CO_2	1.27	0.67	0.10	6.44	1.52	119.49	2.16	4.48
CH_4	5.6×10^{-3}	3.9×10^{-3}	4.0×10^{-4}	0.02	5.0×10^{-3}	89.29	2.25	6.11
N_2O	2.0×10^{-4}	2.0×10^{-4}	4.0×10^{-5}	7.0×10^{-4}	2.0×10^{-4}	100.00	1.50	1.76
NH_3	1.1×10^{-3}	9.0×10^{-4}	1.0×10^{-4}	3.5×10^{-3}	9.0×10^{-4}	81.82	1.41	1.72
NMVOC	2.1×10^{-3}	1.5×10^{-3}	3.0×10^{-4}	8.9×10^{-3}	1.9×10^{-3}	90.48	2.13	5.43
PM2.5	4.0×10^{-4}	3.0×10^{-4}	4.0×10^{-5}	8.0×10^{-4}	2.0×10^{-4}	50.00	0.34	−0.58
PM10	5.0×10^{-4}	5.0×10^{-4}	1.0×10^{-4}	1.2×10^{-3}	3.0×10^{-4}	60.00	0.49	0.34
SO_x	6.0×10^{-4}	4.0×10^{-4}	4.0×10^{-5}	1.9×10^{-3}	5.0×10^{-4}	83.33	1.32	1.24
NO_x	2.6×10^{-3}	1.6×10^{-3}	3.0×10^{-4}	0.02	3.3×10^{-3}	126.92	3.41	13.68

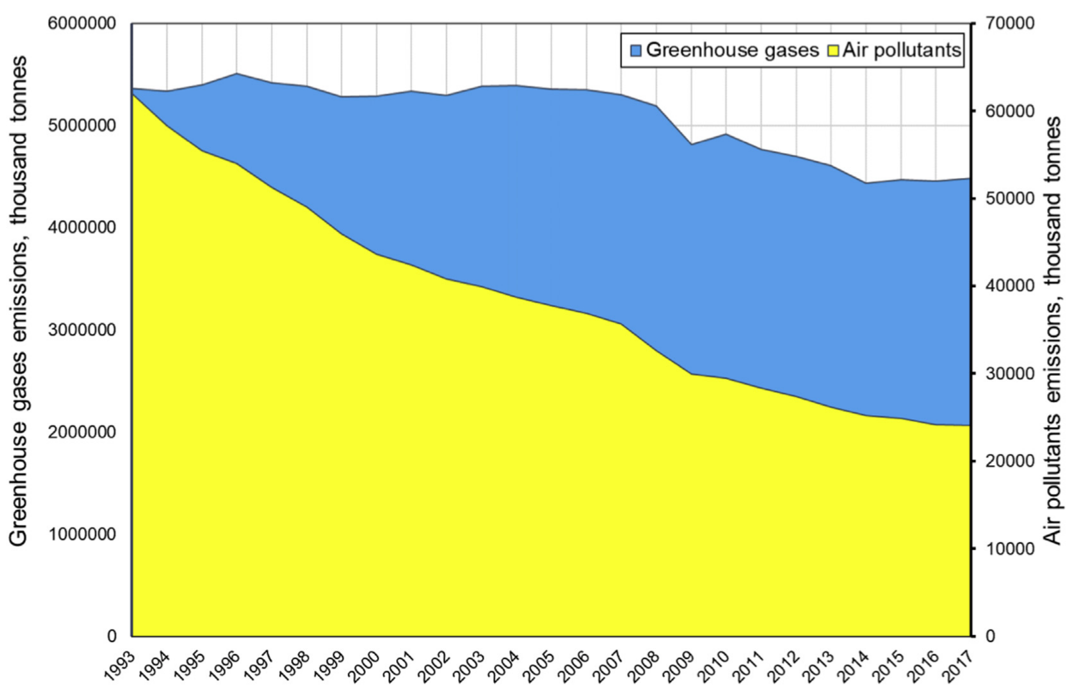

Fig. 1. Total greenhouse gas and air pollutant emissions between 1993 and 2017 in the EU.

dimensional weights $w = [w1, w2, \ldots wd]$, where d is the dimension of input vectors (x) (Balbinot et al., 2005; Garcia et al., 2007; Silva et al., 2008; Zupan and Gasteiger,1991, 1999).

Weights can subsequently be defined as vectors of numbers, where each number is associated with a specific variable of the input vector (x).

According to the values of the weights, which are estimated by the neural network, the variables specified in an object will be more representative for the description of this object and its location within a given neuron. The output data is calculated on the basis of estimating the distance between each input vector (x) and all weight vectors (w), in accordance with Equation (1), where j is a specific neuron; n is the number of neurons; m is the number of weights according to the neuron; and s is a specific

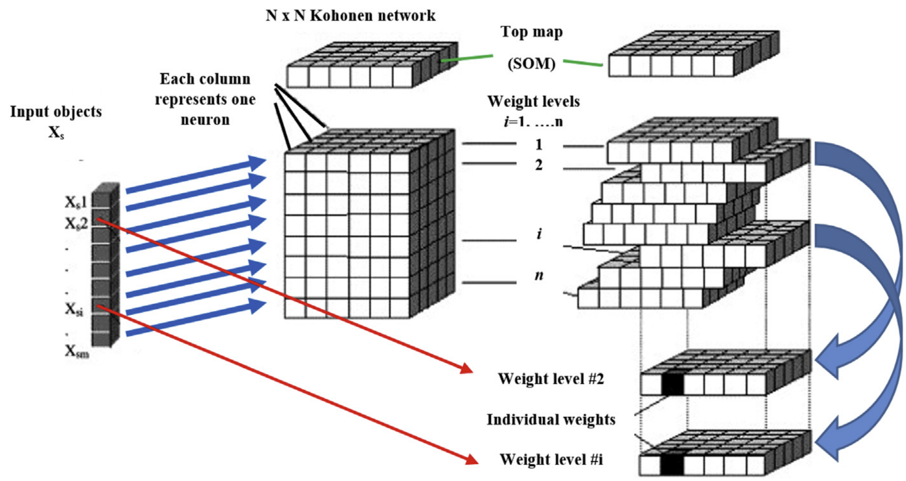

Fig. 2. Scheme of a Kohonen's neural network (own elaboration based on Marini et al. (2005).

input:

$$Output \leftarrow \left[\sum_{i=1}^{m}(x_{si}-w_{ji})^2\right] j = 1,2\ldots n \quad (1)$$

The so-called winning neuron is selected during the learning process, based on the proximity between its weight vector (w) and the input vector (x). The winning neuron exhibits the smallest difference between the w and x values (equation (1), above). The training of the Kohonen's neural network is based on competitive learning, because the active layer neurons compete for activation, on the condition that only one neuron will be selected after each input. This competitive strategy promotes the identification of important functions in detecting input patterns (Balbinot et al., 2005; Garcia et al., 2007; Lek and Guégan, 1999; Silva et al., 2008; Zupan and Gasteiger,1991, 1999).

Each neuron is represented by an m-dimensional weight vector $w = [w_1,\ldots,w_m]$, where m is equal to the dimension of the input vectors.

The Kohonen's network learning algorithm consists of the following stages, the aim of which is to:

1) determine the dimensions of the topological map;
2) initiate initial weight vectors;
3) choose the learning case (observation);
4) calculate the value of the decision function for all neurons and select the winning neuron;
5) determine the neurons neighbouring the winning neuron based on the value of the neighborhood function;
6) adjust the neighbouring neuron weights using the learning factor;
7) modify the learning coefficient and neighborhood size;
8) return to the implementation of point 2, if the conditions for completing network learning are not met.

Euclidean measure was used to calculate the distance between input data (x_{ij}) and neuron weights (w_{ij}).

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

The winning neuron (M) is calculated as:

$$D_E(x,w) = {}_i^{min}|d(x,\ w)|$$

The Kohonen's neural network updates the weight vector of the unit i using the self-organization learning rule as:

$$w_{ij}\ (t+1) = w_{ij}t + \alpha(t)h_{ci}(r_{ij}(t))\ [x_{ij}(t) - w_{ij\ (t)}] \quad (3)$$

where: t is time, $\alpha(t)$ is the learning rate and ranges between [0,1], and $h_{ci}(r_{ij}(t))$ is the neighborhood kernel around the winner unit c with a neighborhood distance $r_{ij}(t)$. If a small learning rate is taken, the model will take a very long time to converge. In turn, if the learning rate is large, the result in unstable learning, because it may step over a minimum. In this study, a constant value of 0.1 was selected for $\alpha(t)$. The process of modeling is repeated until the maximum number of iterations (t_{max}) is reached or the change in the weight magnitudes is less than the specified threshold (Rahmati et al., 2019).

3. Results

Based on the presented data and discussed method, the analysis was conducted, the results of which are presented in this chapter. As mentioned before, the purpose of this analysis was to divide 28 EU countries into similar groups in terms of the emission volume of carbon dioxide, methane, nitrous oxide, ammonia, non-methane volatile organic compounds, PM2.5, PM10, and sulfur oxide. The analysis was carried out in terms of the absolute values of studied parameters. Afterwards, these values were compared to the number of inhabitants and the value of GDP for individual countries. In addition, the comparative analysis of the emissions of studied substances between 2007 and 2017 was also performed. The purpose of this analysis was to determine the impact of the EU policy and changes in the public awareness of environmental protection on the change in emissions of individual substances over a 10-year period.

3.1. Analysis of greenhouse gas and pollutant emissions by the EU countries between 2007 and 2017

One of the EU's strategic goals related to reducing the negative impact of anthropogenic activities on the environment is to reduce greenhouse gas emissions and atmospheric pollution. Over the past 10 years, intensive efforts have been made to decrease this emission. When analyzing the emission values, it can be stated that between 2007 and 2017 greenhouse gas emissions in the EU countries were reduced by a total of 15.5%, and pollutant emissions by 32.4%.

The amounts of greenhouse gas emissions in individual EU countries between 2007 and 2017 are shown in Fig. 3. Fig. 4 shows the percentage changes in the emissions of these gases between 2007 and 2017.

When analyzing the results, the undisputed leaders in reducing greenhouse gas emissions into the atmosphere during this period were Denmark and Finland. These countries decreased this emission by nearly 30%. Both United Kingdom and Greece were found to have achieved very good results as well. Poland was reported to have the lowest result, showing the reduction in greenhouse gas emissions at a level of only around 1%. This is the consequence of Poland's energy policy, in which hard and brown coal remains invariably the main energy resource.

A similar analysis, was made with regard to the emissions of gaseous and particulate pollutants. The emission of air pollutants in individual countries is shown in Fig. 5, and the percentage changes over the studied period of time in Fig. 6.

With regard to the reduction of gaseous and particulate pollutant emissions into the atmosphere between 2007 and 2017, Bulgaria, Greece and Malta were shown to have achieved the best results (reduction by over 60%). The lowest result was obtained by Hungary, which decreased the emission level by just over 8%.

Detailed changes in the emissions of studied gases and particulates between 2007 and 2017 are presented in Fig. 7.

It was found that the emission of studied substances in the studied period significantly decreased. However, the dynamics of these changes differed significantly between the EU countries. Despite the unambiguous and clear EU policy to reduce harmful substance emissions, several countries were reported to have significant increases in some of these substances.

An increase in methane emissions was reported in Ireland (approx. 9%), Croatia (over 2.5%), Cyprus (6.93%), Latvia (0.57%) and Luxembourg (2.55%), while an increase in N_2O emissions was noted in Bulgaria (33.18%), the Czech Republic (0.98%), Estonia (17.18%), Ireland (6.74%), Latvia (12.81%) and Luxembourg (5.94%). The NH_3 emissions were observed to be increased in Germany (4.29%), Ireland (9.22%), Spain (1.36%), France (0.88%), Latvia (5.58%), and Luxembourg (0.75%). In terms of PM2.5 emissions, increases were reported in Bulgaria (2.84%) and Hungary (19.59%). For PM 10 emissions, they were found to be elevated in Hungary (by 11.39%).

The results indicate that in more developed countries, pro-ecological actions bring better relative results in the scope of limiting the emission of harmful substances. Therefore, it can be said that in prosperous countries, the rate of reduction of greenhouse gas and pollutant emissions is much higher than in less prosperous countries (Lapinskienė et al., 2014). On the other hand, with regard to the absolute values, the emission of greenhouse gas and air pollutants in prosperous countries is more elevated when compared to less prosperous countries.

These results allow for an accurate ranking of the EU countries in terms of the amount of harmful substances emitted into the atmosphere.

Nevertheless, it seems reasonable to adopt a deeper approach to analyzing the obtained data. Without a doubt, it would be advisable to additionally determine the similarities between individual countries in terms of the emissions of studied substances. This division gives an opportunity to assess the effectiveness of introducing changes and to develop either joint or similar programs in the field of reducing harmful greenhouse gas and air pollutant emissions into the environment.

As mentioned earlier, in order to take into account the specificity of individual countries, especially in terms of their wealthiness and number of inhabitants, further analysis was carried out by comparing the volume of the emissions of studied substances to these parameters.

3.2. *Division of the EU countries into homogeneous groups based on greenhouse gas and air pollutant emissions*

The first stage of the basic analysis involved grouping the EU countries by the volume of the emissions of studied greenhouse gases and air pollutants. The analysis was based on the data presented in Table 1 regarding emissions from 2017.

The Kohonen's neural network was used for the analysis. It is dedicated to study multidimensional input data in order to present

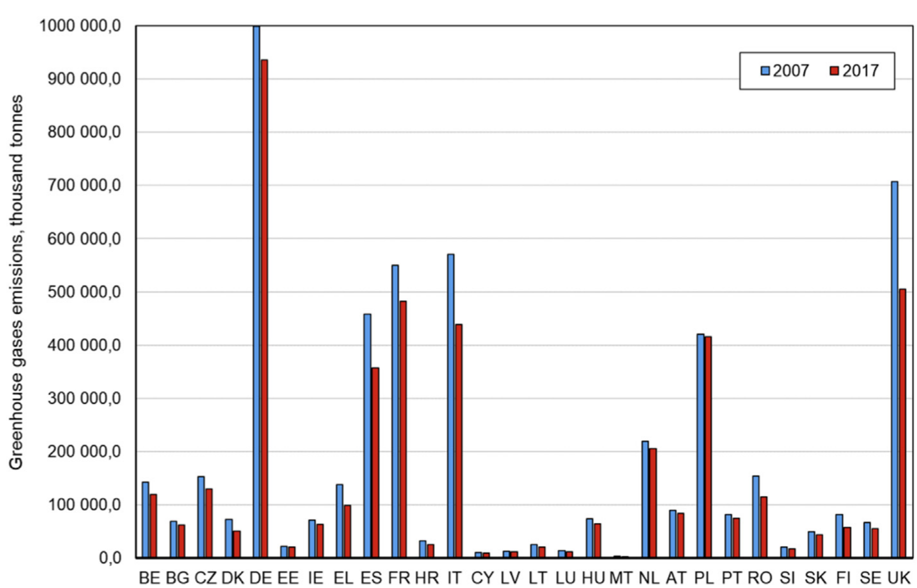

Fig. 3. The amount of greenhouse gas emissions in individual EU countries between 2007 and 2017 (BE-Belgium, BG- Bulgaria, CZ-Czech Republic, DK-Denmark, DE-Germany, EE-Estonia, IE-Ireland, EL-Greece, ES-Spain, FR-France, HR-Croatia, IT-Italy, CY-Cyprus, LV-Latvia, LU-Lithuania, LU- Luxembourg, HU-Hungary, MT-Malta, NL-Netherlands, AT-Austria, PL-Poland, PT-Portugal, RO-Romania, SI-Slovenia, SK-Slovak Republic, Fi-Finland, SE-Sweden, UK-United Kingdom).

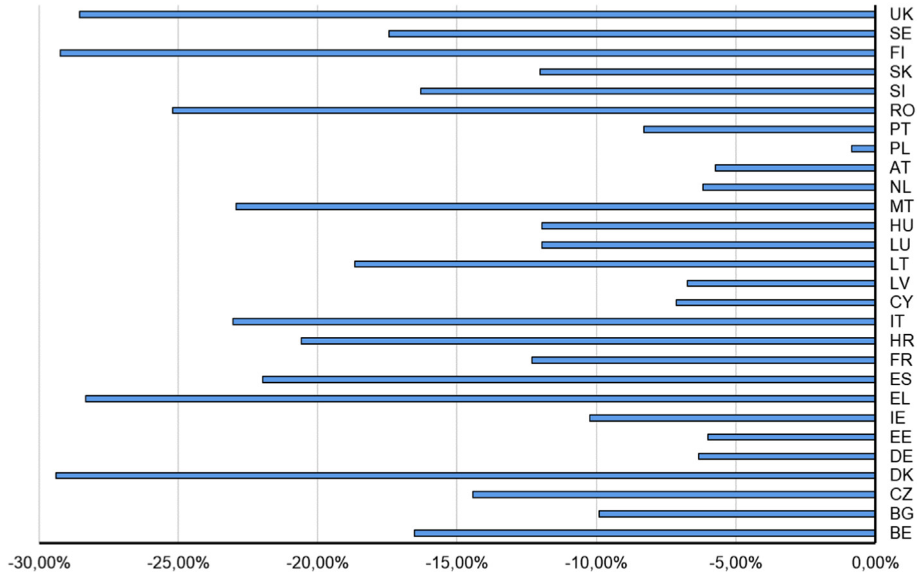

Fig. 4. Changes in greenhouse gas emissions in the EU countries between 2007 and 2017.

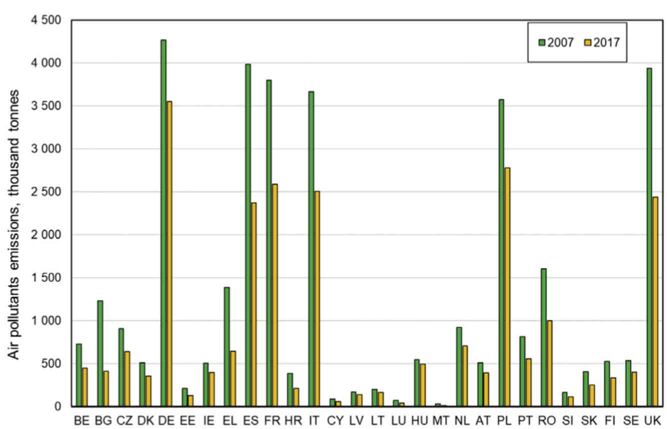

Fig. 5. Air pollutant emissions in the EU countries between 2007 and 2017.

it in a smaller, more readable number of dimensions. When using this method, it is crucial to determine the topology of the net used.

The number of neurons of the topological net was selected based on the analysis performed by the Ward's agglomeration method, in which it was calculated that the number of clusters should be 4. This number of neurons (clusters) is also confirmed by the following relationship (Mardia et al., 1979):

$$k \cong \sqrt{\frac{n}{2}} \tag{4}$$

where: k − number of neurons, n − number of countries.

In the initial stage of the analysis, the dimensions of the topological map, i.e. the output layer of the network, were determined. The topological map has the form of a two-dimensional square net and consists of two rows and two columns. The net nodes comprised four clusters reflecting the "traces" of the wins of each of the radial neurons, which is also a detector of similar countries presented at the entrance to the network.

As many as 28 countries were divided into four internally homogeneous clusters, taking into account the volume of the emissions of studied greenhouse gases and air pollutants. It is important that the similarity between these countries is not based on the total emissions of all studied substances, but on the volume of the emissions of each of them individually.

Based on the calculations carried out, the EU Member States were assigned to 4 clusters in terms of the emissions of studied substances. Their composition with the values of the activation function (distance from the center of the cluster) is presented in Table 6.

Countries within one cluster are most similar in terms of greenhouse gas and pollutant emissions, and at the same time significantly different from countries in other clusters.

The topological map of these clusters is shown in Fig. 8. This map maintains non-linear relationships between the EU countries and places similar countries closely to each other on the map.

The number of countries within the clusters varies greatly, from 2 countries (cluster 3) to 13 countries (cluster 1). The results indicate that in terms of the emissions in 2017, there was no homogeneity of any of the EU countries (no country constitutes a separate cluster).

Based on the results, countries with the lowest emissions were found in cluster 1, while countries with the highest emissions were found in cluster 2.

The emissions of studied substances by the countries in individual clusters are presented in Fig. 9. In order to show the level of greenhouse gas and air pollutant emissions, a uniform scale was used.

The analysis showed that the countries in cluster 2 were reported to have the highest greenhouse gas and air pollutant emissions into the atmosphere in 2017. These countries include France, Germany, Poland, Great Britain, Spain, and Italy. The most pollutants from this cluster (total emissions of all substances) were emitted by Germany, Great Britain, France and Italy, respectively, while the least by Poland and Spain.

Greenhouse gas and air pollutant emissions in Germany in 2017 amounted to around 20% of the EU emissions of these substances, in Great Britain about 13.5%, in Italy about 11%, and in France about 9%. The share of Spain was around 8.65% and of Poland 7.7%. Undoubtedly, these EU countries dominate in terms of air pollution.

It is interesting to look at the ratio between the emissions of studied substances by Germany, as the largest emitter in the EU, and the emissions of other countries in cluster 2 (Table 7).

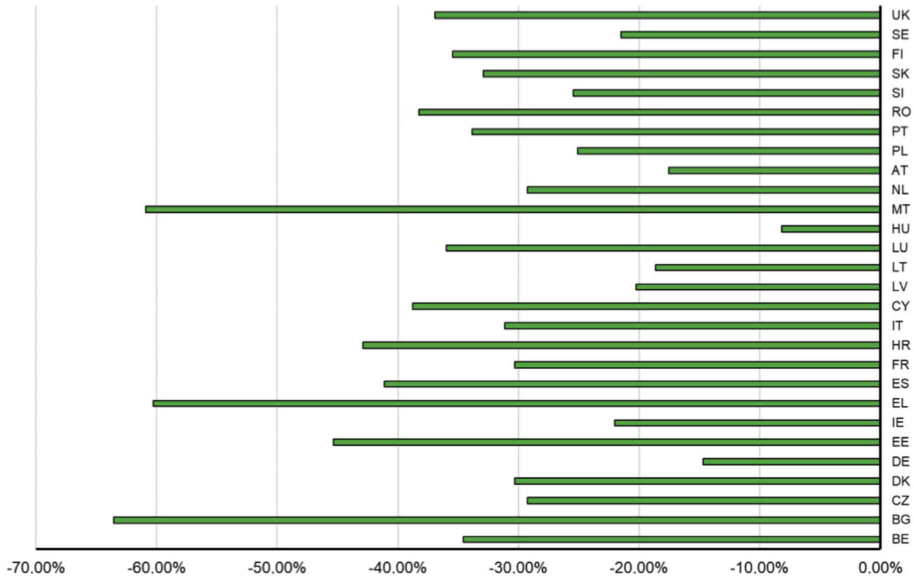

Fig. 6. Changes in air pollutant emissions in the EU countries between 2007 and 2017.

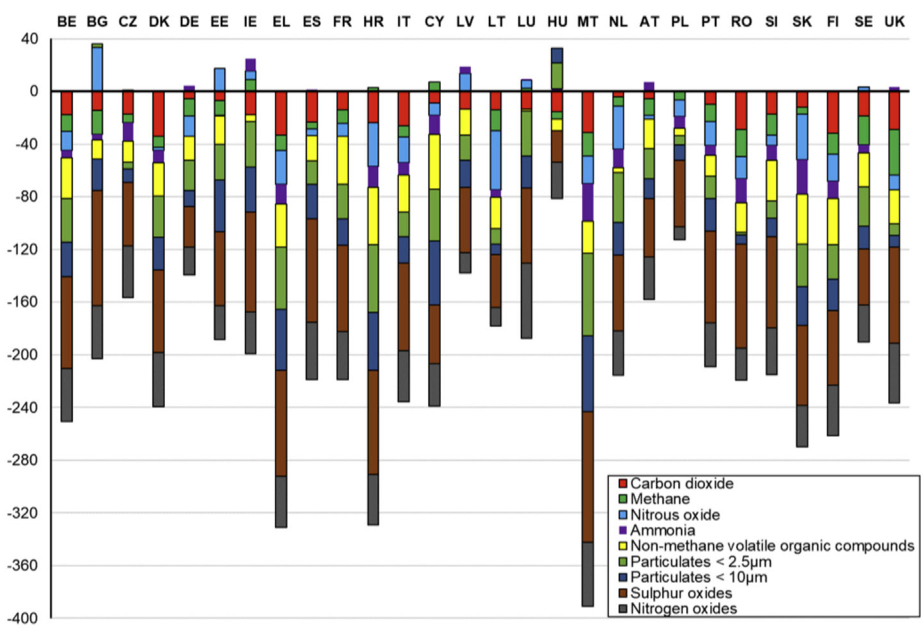

Fig. 7. Cumulative percentage reduction in gaseous and particulate pollutant emissions between 2007 and 2017.

Based on the results (Table 7), it can be stated that Germany is not, as it may seem, the largest emitter of all substances among the countries in cluster 2. In fact, Germany is the largest emitter of "only" carbon dioxide, methane and NMVOC, namely three of nine studied substances.

Carbon dioxide emissions in Germany are by far doubled in Spain, Italy, Poland and France, and ammonia in Poland and the United Kingdom. It is worth noting that in terms of PM2.5 emissions, Germany is the "smallest" emitter among all the countries in cluster 2, while in the case of PM10, its emission in Germany is lower than in France and Poland.

It is also worth noting that in almost all countries from cluster 2, the level of NO_x emissions, except for Germany, is at a very similar level (Fig. 9b). High NO_2 emissions result from the fact that they mainly come from car exhaust gases. Its presence in the air is associated with increased car traffic in urban areas in Great Britain, France, Germany, Spain, and Italy. In the case of Poland, the level of NO_2 is at a slightly lower level. However, the emission of these oxides in Poland is due to their emission from domestic furnaces and local coal-fired boilers.

The composition of cluster 1 is also worth attention. It comprises Austria (one of the largest emitters of studied substances into the atmosphere in this cluster) and Malta, which was found to emit the lowest amount of these substances in the entire EU (also in cluster 1). Malta, compared to Austria, emits more than 35 times less gaseous and particulate pollutants into the atmosphere.

The ratio between greenhouse gas and air pollutant emissions into the atmosphere by Austria, the largest emitter from cluster 1, and the level of emissions by other countries from this cluster is presented in Table 8.

Table 6
Composition of clusters and distance from the center of a given cluster (value of activation function).

Elements of clusters 1	Value of the activation function	Elements of clusters 2	Value of the activation function	Elements of clusters 3	Value of the activation function	Elements of clusters 4	Value of the activation function
Denmark	0.167	Germany	0.794	Ireland	0.258	Belgium	0.153
Estonia	0.081	Spain	0.437	Netherlands	0.003	Bulgaria	0.124
Croatia	0.047	France	0.729			Czech Republic	0.138
Cyprus	0.130	Italy	0.489			Greece	0.143
Latvia	0.059	Poland	0.598			Hungary	0.115
Lithuania	0.040	United Kingdom	0.439			Portugal	0.123
Luxembourg	0.133					Romania	0.706
Malta	0.153						
Austria	0.158						
Slovenia	0.060						
Slovak Republic	0.065						
Finland	0.126						
Sweden	0.171						

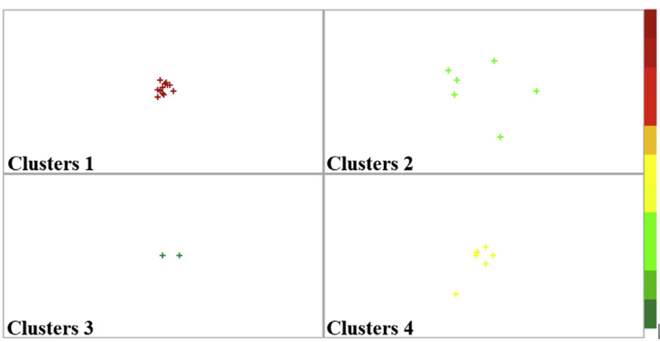

Fig. 8. Topological map of the Kohonen's neural network that groups the EU countries in terms of the similarities in the volume of emissions of studied greenhouse gases and air pollutants.

The results (Table 8) clearly show that the differences between the largest emitter of greenhouse gases and air pollutants from cluster 1, i.e. Austria, and the remaining countries are much bigger versus the differences between the largest emitter - Germany and the other countries from cluster 2.

The emission level by Austria is many times higher than the emission levels by other countries from the same cluster. This applies especially to the emissions of carbon dioxide and nitrogen oxides, as they are many times higher than in other countries from this cluster (compared to Malta over 35 times higher, compared to Latvia almost 10 times higher). Also, the level of ammonia emissions is much higher than in other countries from this cluster (except for Denmark). For years, Austria has been one of the EU countries exceeding the limits associated with the level of ammonia and NO_X emissions.

It is worth noting that for all studied substances, Austria is a larger emitter than Malta, Slovenia and Luxembourg.

The smallest differences in terms of studied emissions were observed between Austria and Denmark, followed by Austria, Finland and Sweden. However, Denmark, Sweden and Finland (Scandinavian countries) were reported to be larger emitters of N_2O, PM2.5 and PM10. In addition, Denmark was found to emit more methane and ammonia than Austria.

The ratios between the level of greenhouse gas and air pollutant emissions into the atmosphere by the largest total emitters from clusters 3 and 4 are presented in Tables 9 and 10 respectively.

Similarly to clusters 1 and 2, quite large differences in the relationship between individual emitted substances were observed in cluster 4.

When analyzing the results, it should be remembered that the countries in individual clusters differ from each other in many respects, e.g. the structure of sources from which energy is produced, the number of inhabitants, wealthiness, the economic structure, as well as the structure of the transport sector.

Basic statistics related to the emissions of studied substances into the atmosphere were also calculated for each cluster. Both the total and mean emission values of studied substances for individual clusters were also determined (Table 11). This data helps to characterize each cluster, as each of them is created by a different number of the EU countries.

The following comparison (Table 11) clearly shows that the greatest amount of greenhouse gases and air pollutants in total was emitted in 2017 by the countries in cluster 2, and the smallest amount by the countries in cluster 3.

In relation to the mean value, which takes into account the number of countries in a given cluster, the lowest average level of emissions was reported for the countries in cluster 1.

A more comprehensive analysis of the EU countries from individual clusters is possible based on the coefficients of skewness and kurtosis that focus on the asymmetry and concentration of results around the mean value.

The skewness analysis of studied substances emitted by the countries in individual clusters showed that the value of this coefficient is both positive and negative.

In the case of cluster 2, for the countries characterized by the highest emission of studied substances, the skewness coefficient takes positive values for 8 (out of 9) studied substances. This factor was found to have the highest positive value for carbon dioxide, NO_x and SO_x, which means that the emission of these gases by most countries from cluster 1 is much lower than the mean value of the emissions for the whole cluster. The negative value applies only to methane emissions. This means that the level of gas emissions in most countries exceeds the mean value (for 4 out of 6 countries).

For the countries in cluster 1 with the lowest level of the emissions of studied substances, the skewness coefficient is positive for 7 of them and negative for 2 of them (for air pollutants). A negative skew for PM2.5 and PM10 means that in most countries from this cluster, the level of emissions exceeds the mean value determined for the whole cluster.

The analysis of the skewness coefficient for cluster 4 also showed interesting results. In this cluster, this coefficient is negative only for SO_x and positive for other substances. The level of methane, ammonia and SO_x emissions by the countries from this cluster significantly exceeds the mean emission value determined for this cluster.

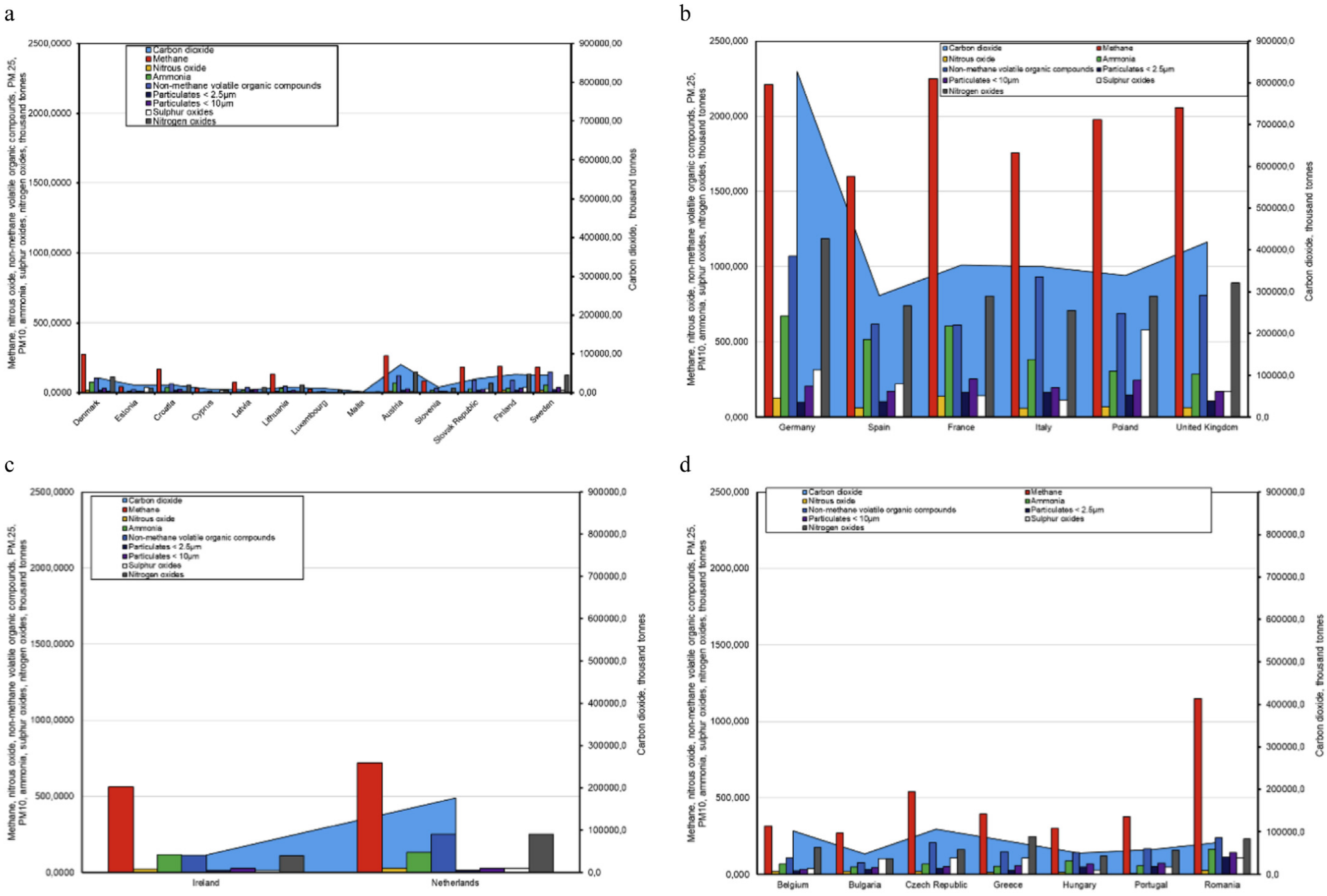

Fig. 9. Emissions of studied substances by the countries in individual clusters (a - cluster 1; b - cluster 2; c - cluster 3; d - cluster 4).

Table 7
The ratio between the emissions of studied greenhouse gases and air pollutants by Germany, as the largest emitter in the EU, and the emissions by other countries in cluster 2.

	CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SO_x	NO_x
Germany-Spain	2.84	1.38	2.06	1.30	1.73	0.94	1.20	1.43	1.61
Germany - France	2.27	0.98	0.90	1.11	1.75	0.60	0.81	2.19	1.47
Germany - Italy	2.30	1.26	2.12	1.75	1.14	0.60	1.05	2.74	1.67
Germany - Poland	2.44	1.12	1.81	2.19	1.55	0.67	0.84	0.54	1.48
Germany -UK	1.97	1.07	1.97	2.38	1.32	0.93	1.21	1.82	1.33

Table 8
The ratio between gas and particulate emissions into the atmosphere by Austria, the largest emitter from cluster 1, and the level of emissions by other countries from this cluster.

	CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SO_x	NO_x
Austria/Denmark	1.92	0.96	0.64	0.91	1.18	0.78	0.90	1.25	1.29
Austria/Estonia	3.83	6.16	3.83	6.74	5.40	1.69	2.01	0.33	4.36
Austria/Croatia	3.77	1.61	2.06	1.84	1.90	0.93	1.10	1.02	2.64
Austria/Cyprus	8.46	7.64	12.00	10.65	9.75	12.10	13.60	0.78	9.95
Austria/Latvia	9.43	3.66	1.73	4.18	3.15	0.87	1.12	3.21	3.87
Austria/Lithuania	5.26	2.03	1.16	2.34	2.63	1.72	1.97	0.97	2.71
Austria/Luxembourg	6.61	11.11	10.99	11.90	9.93	11.61	13.94	12.67	7.90
Austria/Malta	35.47	35.19	78.40	62.08	42.70	65.60	73.92	84.83	27.08
Austria/Slovenia	5.04	3.14	5.00	3.71	4.03	1.36	2.15	2.63	4.17
Austria/Slovak Republic	2.00	1.43	1.82	2.60	1.34	0.86	1.24	0.47	2.20
Austria/Finland	1.54	1.43	0.75	2.22	1.36	0.88	0.96	0.37	1.11
Austria/Sweden	1.61	1.46	0.72	1.30	0.82	0.78	0.69	0.73	1.17

Table 9
The ratio of the volume of emissions of studied greenhouse gases and air pollutants into the atmosphere between Ireland and the Netherlands.

	CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SO_x	NO_x
Ireland - Netherlands	4.23	1.28	1.29	1.11	2.22	1.17	0.99	2.03	2.28

Table 10
The ratio of the volume of emissions of studied greenhouse gases and air pollutants into the atmosphere between the Czech Republic and other countries from cluster 4.

	CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SO_x	NO_x
Czech Republic - Belgium	1.04	1.69	0.98	1.00	1.90	1.73	1.53	2.93	0.93
Czech Republic - Bulgaria	2.22	1.99	1.09	1.36	2.68	1.25	1.09	1.07	1.59
Czech Republic - Greece	1.36	1.36	1.34	1.21	1.40	1.55	0.91	1.04	0.65
Czech Republic - Hungray	2.12	1.79	1.25	0.76	1.47	0.83	0.74	3.97	1.37
Czech Republic - Portugal	1.82	1.43	1.88	1.16	1.24	0.78	0.70	2.31	1.03
Czech Republic - Romania	1.40	0.47	0.75	0.41	0.86	0.36	0.36	1.03	0.70

Table 11
Statistical data on the emissions of studied substances for individual clusters.

		CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SOx	NOx	Sum
Cluster 1	Sum	332946.75	1647.82	98.87	382.40	773.55	159.00	246.99	193.50	828.03	337276.89
	Min	2036.24	7.50	0.15	1.11	2.82	0.24	0.38	0.15	5.34	
	Max	72224.81	275.38	18.29	76.33	146.94	20.10	40.30	38.65	144.71	
	Median	18833.81	130.29	6.47	26.55	45.73	15.61	22.59	12.81	53.44	
	Ave	25611.29	126.76	7.61	29.42	59.50	12.23	19.00	14.88	63.69	
	Standard deviation	20391.21	89.90	6.30	24.08	46.10	7.39	12.52	12.21	47.82	
	Skewness	1.05	0.28	0.50	0.86	0.54	−0.67	−0.15	0.82	0.60	
	Kurtosis	0.60	−1.14	−1.16	−0.21	−0.87	−1.12	−0.92	−0.12	−1.17	
Cluster 2	Sum	2600871.72	11849.48	522.44	2772.66	4733.64	787.41	1245.10	1550.41	5139.46	2629472.32
	Min	291353.35	1600.54	59.72	283.15	611.96	99.06	170.79	115.17	709.07	
	Max	827082.49	2250.22	140.91	673.25	1068.76	164.68	254.23	582.66	1187.50	
	Median	361932.36	2017.39	67.04	451.19	750.08	127.05	200.84	196.66	805.44	
	Ave	433478.62	1974.91	87.07	462.11	788.94	131.24	207.52	258.40	856.58	
	Standard deviation	197220.07	255.68	36.54	161.57	184.56	30.97	35.87	173.67	174.18	
	Skewness	2.21	−0.52	1.00	0.19	0.65	0.13	0.42	1.67	1.77	
	Kurtosis	5.11	−1.19	−1.48	−2.08	−1.11	−2.88	−1.84	2.76	3.39	
Cluster 3	Sum	218256.84	1282.59	51.92	250.615	365.42	25.97	54.21	40.119	362.21	220689.90
	Min	41764.18	561.37	22.65	118.50	113.35	11.97	26.93	13.22	110.31	
	Max	176492.66	721.22	29.27	132.12	252.07	14.00	27.28	26.90	251.91	
	Median	109128.42	641.295	25.96	125.3075	182.71	12.99	27.10	20.06	181.11	
	Ave	109128.42	641.295	25.96	125.3075	182.71	12.99	27.10	20.06	181.11	
	Standard deviation	95267.42	113.03	4.68	9.63	98.09	1.44	0.25	9.67	100.12	
	Skewness	–	–	–	–	–	–	–	–	–	
	Kurtosis	–	–	–	–	–	–	–	–	–	
Cluster 4	Sum	520279.37	3356.98	124.51	548.04	1090.92	331.99	473.09	538.62	1201.84	527945.37
	Min	48114.00	271.39	10.44	49.44	77.23	23.09	33.41	27.72	102.81	
	Max	106680.92	1149.02	26.29	164.34	240.09	111.93	143.20	109.96	249.54	
	Median	50341.26	301.55	14.60	55.21	109.10	25.81	47.03	37.57	119.28	
	Ave	74325.62	479.57	17.79	78.29	155.85	47.43	67.58	76.95	171.69	
	Standard deviation	23680.39	308.14	4.97	39.89	55.55	30.36	35.88	37.30	53.86	
	Skewness	0.36	2.23	0.37	2.17	0.20	2.00	1.91	−0.45	0.32	
	Kurtosis	−1.57	5.19	0.92	4.93	−0.48	4.45	4.26	−2.46	−0.98	

It is impossible to determine the coefficients of skewness and kurtosis for the countries in cluster 3 since the size of the cluster is too small (two countries).

The analysis of the kurtosis coefficient shows, however, that with regard to cluster 1, it is negative for up to 8 substances, with regard to cluster 2 - for 6 substances, and with regard to cluster 4 - for 4 substances. The higher the absolute value of kurtosis (with its negative value), the higher probability that the countries in a given cluster emit substances at a level significantly different from the calculated mean value for the whole cluster.

3.3. *Division of the EU countries into homogeneous groups based on greenhouse gas and air pollutant emissions in relation to GDP*

The second stage of the analysis involved grouping the EU countries into similar clusters in terms of greenhouse gas and air pollutant emissions related to the GDP of all the countries.

This analysis was aimed at determining the similarities between the EU countries with different levels of economic development and wealthiness in terms of major greenhouse gas and air pollutant emissions.

The results of the calculations made it possible to determine clusters (groups) of similar countries in terms of the level of greenhouse gas and air pollutant emissions related to the GDP value, the location of which is shown in the topological map in Fig. 10. The composition of the clusters is presented in Table 12.

The emissions of studied substances by the countries in individual clusters are presented in Fig. 11. In order to show the level of greenhouse gas and air pollutant emissions, a uniform scale was used.

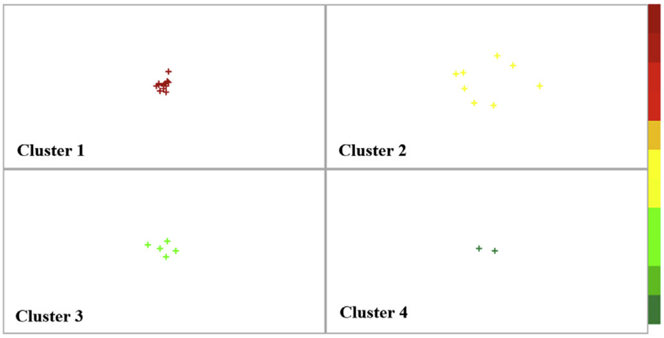

Fig. 10. Topological map of the Kohonen's neural network grouping the EU countries in terms of the similarities between the volume of emissions of studied greenhouse gases and air pollutants and the GDP value of a given country.

The analysis showed that the countries with the highest emissions of studied greenhouse gases and air pollutants into the atmosphere in 2017, converted into the GDP value of a given country, were assigned (as in the previous variant of analysis) to cluster 2. These countries include Bulgaria, Estonia, Croatia, Latvia, Lithuania, Hungary, Poland, and Romania. All these countries are classified as relatively new in the EU in relation to the EU structure often referred to as EU15 (they joined the EU in 2004 and 2007, or later).

Most of these countries can be classified as developing economies that are characterized by a high level of greenhouse gas emissions and air pollution in relation to the GDP value (The Poland Competitiveness Report, 2017).

The five largest countries in terms of production volume (including the GDP value), i.e. Germany, Great Britain, France, Italy (Cluster 1) and Spain (Cluster 4) together produce almost 71% of GDP - calculated according to the ECB reference rates (the euro foreign exchange reference rates), or 67% - according to the purchasing power parity (PPP) (The Poland Competitiveness Report, 2017). These countries were found in clusters with low emissions of greenhouse gases and air pollutants in relation to GDP. These results indicate large differences between the so-called “Old Union” and “New” Member States (and more broadly - between Western Europe and Central and Eastern Europe). The determined values are relative, but they quite clearly reveal the prosperity limit of the EU countries. It can also be seen that for less prosperous countries, the costs associated with reducing the emissions of harmful substances are relatively higher than for countries with a higher GDP value.

Statistical data on the emissions of studied substances in relation to the GDP value for individual clusters is presented in Table 13.

When analyzing the results from Table 13, it can be concluded that the largest amounts (emissions in total) of greenhouse gases and air pollutants in 2017 in terms of GDP were emitted by the countries from cluster 2, and the smallest amounts by the countries from cluster 4. However, the lowest mean level of the emissions of studied greenhouse gases and air pollutants was noted in the countries from cluster 1.

The highest amount of studied substances emitted by the countries in all clusters concern carbon dioxide, methane, NMVOC, and ammonia.

The skewness analysis showed both positive and negative values in all clusters and for all studied substances.

The highest positive value of the skewness coefficient was obtained for NO_X emission related to the GDP value. It amounted to 2.17 for cluster 3. However, the smallest positive value of this coefficient was obtained for SO_X emissions in relation to the GDP value and amounted to 0.05 (also for cluster 3).

The smallest negative value of the skewness coefficient was determined for PM2.5 emissions (−0.77), and the largest negative value for NVOMC emissions (−0.05). These values were also reported for cluster 3.

3.4. Division of the EU countries into homogeneous groups based on greenhouse gas and air pollutant emissions per capita

The third option of grouping countries into homogeneous clusters (groups) included the comparison of the volume of the emissions of studied substances to the number of inhabitants of a given country. This allowed the authors to determine the volume of emissions of these substances per capita of each EU country. As in the previous analyses, the results differ significantly from the division according to the absolute volume of studied emissions.

As in the case of the previous two variants, the EU countries were grouped into four clusters (Table 14).

The topological map of the created clusters is presented in Fig. 12. The structure and volume of gas and dust emissions in relation to the number of inhabitants in individual clusters is presented in Fig. 13.

The analysis showed that the countries with the highest level of the emissions of studied greenhouse gases and air pollutants into the atmosphere in 2017 in relation to the number of inhabitants were assigned (as in the previous analysis variants) to cluster 2. These countries include the Czech Republic, Denmark, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Poland, and Finland. The composition of this cluster is quite interesting because Denmark, Estonia, Latvia, Lithuania and Finland in the first variant of the analysis were assigned to the countries with the lowest levels of greenhouse gas emissions and air pollutants.

Poland, as in the previous two variants of the analysis, is the only country with one of the highest levels of harmful emissions into the atmosphere, regardless of the factor included in the analysis.

Table 12
Composition of clusters and distance from the center of a given cluster (value of activation function).

Elements of clusters 1	Value of the activation function	Elements of clusters 2	Value of the activation function	Elements of clusters 3	Value of the activation function	Elements of clusters 4	Value of the activation function
Belgium	0.098	Bulgaria	1.182	Czech Republic	0.309	Spain	0.222
Denmark	0.157	Estonia	0.736	Greece	0.403	Cyprus	0.217
Germany	0.093	Croatia	0.479	Portugal	0.190		
Ireland	0.380	Latvia	0.739	Slovenia	0.260		
France	0.162	Lithuania	0.617	Slovak Republic	0.133		
Italy	0.203	Hungary	0.518				
Luxembourg	0.166	Poland	0.499				
Malta	0.162	Romania	0.760				
Netherlands	0.097						
Austria	0.032						
Finland	0.193						
Sweden	0.173						
United Kingdom	0.076						

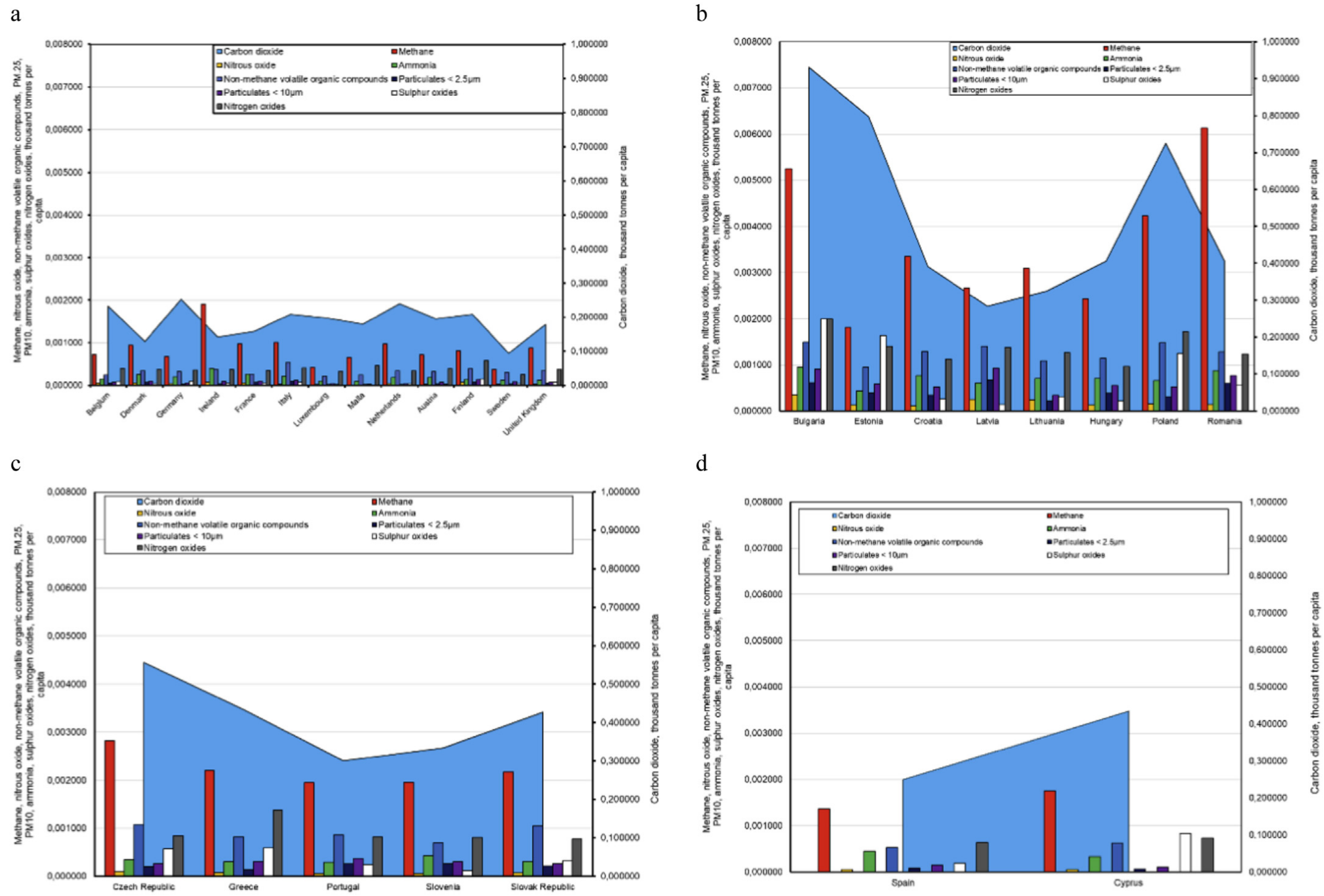

Fig. 11. Emissions of studied substances in relation to GDP for countries in individual clusters (a – cluster 1; b - cluster 2; c - cluster 3; d - cluster 4).

This time, the analysis showed the homogeneity of one country - Bulgaria. When considering the number of inhabitants, this country does not show any similarities in terms of the level of emissions in other countries that would allow it to belong to other clusters.

It is clear that the demographic factor significantly changed the composition of similar groups. Countries with a large population size, even with high emissions of harmful substances, were in cluster 1. Undoubtedly, as in the previous analyses, the countries from cluster 2 were reported to have the most unfavorable indicator of the emission per capita.

Statistical data on the emissions of studied substances per capita for individual clusters is presented in Table 15.

When considering the number of inhabitants of a given country, the analysis clearly shows that the highest level of the emissions of studied substances occurs in cluster 2, and the lowest in cluster 4. However, when taking into account the number of countries forming the clusters and the mean value of the emissions, it appears that the countries from cluster 1 report the lowest mean emissions.

The highest emissions of studied substances by the countries in individual clusters concern carbon dioxide, methane, NMVOC, and ammonia.

The analysis of the skewness coefficient showed positive values for all studied substances in cluster 2. Therefore, the right-sided asymmetry was reported for the studied substances. This means that the level of the emissions of studied substances by the countries from cluster 2 is at a level lower than the mean value determined for this cluster. However, some countries, including Ireland and Poland, emit substances significantly above the mean value for cluster 2.

3.5. Division of the EU countries into homogeneous groups by greenhouse gas and air pollutant emissions per surface area of a given country

The last variant of grouping countries into homogeneous clusters involved the comparison of the volume of studied emissions to the surface area of a given country. This made it possible to determine the emissions of these substances per 1 km2 of each EU country. As in the previous analyses, the results differed significantly from the division, depending on the absolute volume of emissions.

Similarly to the previous variants, the EU countries were grouped into four clusters. Their composition together with the value of the activation function is presented in Table 16.

The topological map of the created clusters is presented in Fig. 14. The structure and volume of gas and dust emissions in relation to the surface area of countries in individual clusters are presented in Fig. 15.

Statistical data on the emissions of studied substances per 1 km2 of area for individual clusters is presented in Table 17.

The analysis of the results shows that the division of the countries into homogeneous clusters by the structure and volume of greenhouse gas and air pollutant emissions per 1 km2 of their

Table 13
Statistical data on the emissions of studied substances in relation to the GDP value for individual clusters.

		CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SOx	NOx	Sum
Cluster 1	Sum	2.41	0.01	5.6×10^{-4}	2.5×10^{-3}	4.3×10^{-3}	6.3×10^{-4}	1.0×10^{-3}	7.6×10^{-4}	5.0×10^{-3}	2.44
	Min	0.09	3.8×10^{-4}	1.0×10^{-5}	1.0×10^{-4}	2.2×10^{-4}	2.0×10^{-5}	3.0×10^{-5}	1.0×10^{-5}	2.6×10^{-4}	
	Max	0.25	1.9×10^{-3}	8.0×10^{-5}	4.0×10^{-4}	5.4×10^{-4}	1.0×10^{-5}	1.3×10^{-4}	1.6×10^{-4}	5.8×10^{-4}	
	Median	0.20	8.2×10^{-4}	4.0×10^{-5}	1.8×10^{-4}	3.3×10^{-4}	4.0×10^{-5}	8.0×10^{-5}	4.0×10^{-5}	3.8×10^{-4}	
	Ave	0.19	8.5×10^{-4}	4.0×10^{-5}	1.9×10^{-4}	3.3×10^{-4}	5.0×10^{-5}	8.0×10^{-5}	6.0×10^{-5}	3.9×10^{-4}	
	Standard deviation	0.05	3.8×10^{-4}	2.0×10^{-5}	9.0×10^{-5}	8.3×10^{-5}	2.4×10^{-5}	3.1×10^{-5}	3.9×10^{-5}	7.5×10^{-5}	
	Skewness	−0.50	1.82	0.40	1.34	1.20	0.59	−0.12	1.37	1.22	
	Kurtosis	−0.20	5.26	−0.79	2.14	2.61	−0.54	−0.94	2.35	3.25	
Cluster 2	Sum	4.27	0.03	1.5×10^{-3}	5.7×10^{-3}	0.01	3.5×10^{-3}	5.1×10^{-3}	6.4×10^{-3}	1.1×10^{-3}	4.34
	Min	0.28	1.8×10^{-3}	1.2×10^{-4}	4.3×10^{-4}	9.4×10^{-4}	2.2×10^{-4}	3.4×10^{-4}	1.5×10^{-4}	9.6×10^{-4}	
	Max	0.93	6.1×10^{-3}	3.5×10^{-4}	9.6×10^{-4}	1.5×10^{-3}	6.6×10^{-4}	9.3×10^{-4}	2.0×10^{-3}	1.2×10^{-3}	
	Median	0.41	3.2×10^{-3}	1.5×10^{-4}	7.0×10^{-4}	1.3×10^{-3}	3.9×10^{-4}	6.0×10^{-4}	4.4×10^{-4}	1.3×10^{-3}	
	Ave	0.54	3.6×10^{-3}	2.0×10^{-4}	7.0×10^{-4}	1.3×10^{-3}	4.4×10^{-4}	6.4×10^{-4}	7.9×10^{-4}	1.4×10^{-3}	
	Standard deviation	0.25	1.5×10^{-3}	8.0×10^{-5}	1.6×10^{-4}	0.00020	1.6×10^{-4}	2.1×10^{-4}	7.2×10^{-4}	3.3×10^{-4}	
	Skewness	0.73	0.69	1.17	−0.20	−0.41	0.25	0.27	0.82	0.84	
	Kurtosis	−1.34	−0.55	0.38	0.48	−0.95	−1.55	−0.94	−1.14	0.39	
Cluster 3	Sum	2.05	0.01	4.0×10^{-4}	1.7×10^{-4}	4.5×10^{-3}	1.1×10^{-3}	1.5×10^{-3}	1.8×10^{-3}	4.6×10^{-3}	2.09
	Min	0.30	2.0×10^{-3}	5.0×10^{-5}	3.0×10^{-4}	6.9×10^{-4}	1.4×10^{-4}	2.7×10^{-4}	1.1×10^{-4}	7.7×10^{-4}	
	Max	0.56	2.8×10^{-3}	1.0×10^{-4}	4.3×10^{-3}	1.1×10^{-3}	2.7×10^{-4}	3.7×10^{-4}	5.9×10^{-4}	1.4×10^{-3}	
	Median	0.43	2.2×10^{-3}	1.0×10^{-4}	3.0×10^{-4}	9.0×10^{-4}	2.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	8.0×10^{-4}	
	Ave	0.41	2.2×10^{-3}	7.4×10^{-5}	3.4×10^{-4}	9.0×10^{-4}	2.2×10^{-4}	3.1×10^{-4}	3.7×10^{-4}	9.3×10^{-4}	
	Standard deviation	0.10	3.6×10^{-4}	2.0×10^{-5}	6.0×10^{-5}	1.6×10^{-4}	5.0×10^{-5}	4.0×10^{-5}	2.1×10^{-4}	2.6×10^{-4}	
	Skewness	0.57	1.65	0.47	1.61	−0.05	−0.77	1.11	0.05	2.17	
	Kurtosis	−0.11	2.96	−0.83	2.39	−1.87	0.15	1.06	−2.29	4.77	
Cluster 4	Sum	0.68	3.1×10^{-3}	1.0×10^{-4}	8.0×10^{-4}	1.2×10^{-3}	2.0×10^{-4}	3.0×10^{-4}	1.0×10^{-3}	1.4×10^{-3}	0.69
	Min	0.25	1.4×10^{-3}	5.0×10^{-5}	3.3×10^{-4}	5.3×10^{-4}	7.0×10^{-5}	1.0×10^{-4}	1.9×10^{-4}	6.3×10^{-4}	
	Max	0.43	1.8×10^{-3}	5.0×10^{-5}	4.4×10^{-4}	6.3×10^{-4}	9.0×10^{-5}	1.5×10^{-4}	8.3×10^{-4}	7.4×10^{-4}	
	Median	0.34	1.6×10^{-3}	5.0×10^{-5}	3.9×10^{-4}	5.8×10^{-4}	8.0×10^{-5}	1.3×10^{-4}	5.1×10^{-4}	6.9×10^{-4}	
	Ave	0.34	1.6×10^{-3}	5.0×10^{-5}	3.9×10^{-4}	5.8×10^{-4}	8.0×10^{-5}	1.3×10^{-4}	5.1×10^{-4}	6.9×10^{-4}	
	Standard deviation	0.13	2.7×10^{-4}	1.0×10^{-6}	8.0×10^{-5}	7.0×10^{-5}	2.0×10^{-5}	3.0×10^{-5}	4.6×10^{-4}	8.0×10^{-5}	
	Skewness	–	–	–	–	–	–	–	–	–	
	Kurtosis	–	–	–	–	–	–	–	–	–	

Table 14
Composition of clusters and distance from the centre of a given cluster (value of activation function).

Elements of clusters 1	Value of the activation function	Elements of clusters 2	Value of the activation function	Elements of clusters 3	Value of the activation function	Elements of clusters 4	Value of the activation function
Belgium	0.333	Czech Republic	0.635	Greece	0.751	Bulgaria	0.006
Germany	0.365	Denmark	0.613	Croatia	0.217		
Spain	0.447	Estonia	1.121	Hungary	0.294		
France	0.517	Ireland	2.541	Portugal	0.235		
Italy	0.344	Latvia	0.875	Romania	0.682		
Cyprus	0.418	Lithuania	0.587	Slovenia	0.421		
Malta	0.737	Luxembourg	1.344	Slovak Republic	0.368		
Netherlands	0.608	Poland	0.439				
Austria	0.312	Finland	0.641				
Sweden	0.486						
United Kingdom	0.252						

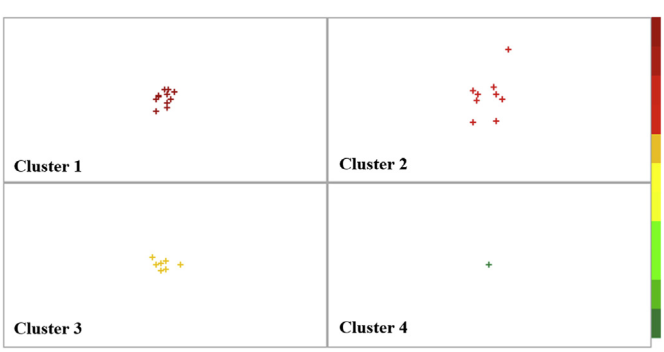

Fig. 12. The Topological map of the Kohonen's neural network grouping the EU countries in terms of the similarities in the volume of emissions of studied greenhouse gases and air pollutants per capita of a given country.

surface area significantly differs from the previously obtained divisions.

Countries with the highest total and mean (per country) level of the emissions of studied greenhouse gases and air pollutants compared to the country's area were found in cluster 1, and countries with the lowest emissions - in cluster 2.

The largest emissions per 1 km^2 were reported to occur in two countries with the smallest surface area among the Member States, i.e. in Luxembourg and Malta, as well as in Belgium and the Netherlands, i.e. countries with a much larger area. In general, however, these countries are located within six countries with the smallest surface area in the EU.

Until now, Malta has been among the countries with the lowest total emissions in terms of both GDP and population. In turn, Luxembourg belong to the countries with the lowest total emissions when compared to GDP. Belgium is the country with the

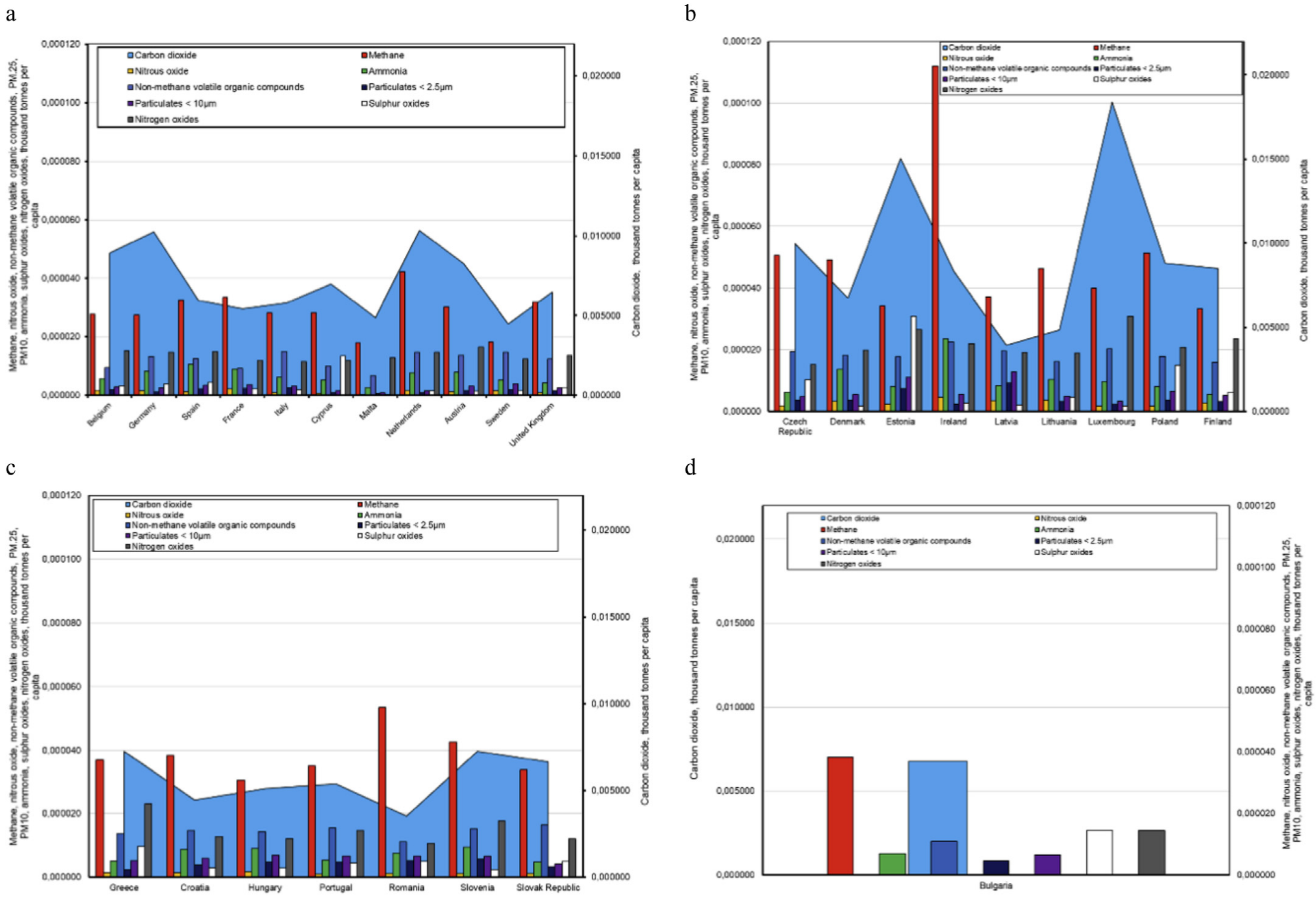

Fig. 13. Emissions of studied substances in relation to the number of inhabitants in the countries from individual clusters (a - cluster 1; b - cluster 2; c - cluster 3; d - cluster 4).

Table 15
Statistical data on the emissions of studied substances per capita for individual clusters.

		CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SOx	NOx	Sum
Cluster 1	Sum	0.08	3.2×10^{-4}	1.0×10^{-5}	7.0×10^{-5}	1.3×10^{-4}	2.0×10^{-5}	3.0×10^{-5}	4.0×10^{-5}	1.5×10^{-4}	0.079
	Min	4.5×10^{-3}	1.8×10^{-5}	4.0×10^{-7}	3.0×10^{-6}	7.0×10^{-6}	6.0×10^{-7}	9.0×10^{-7}	4.0×10^{-7}	1.1×10^{-5}	
	Max	0.01	4.2×10^{-5}	2.0×10^{-6}	1.1×10^{-5}	1.5×10^{-5}	2.7×10^{-6}	4.0×10^{-6}	1.3×10^{-5}	1.7×10^{-5}	
	Median	6.5×10^{-3}	2.8×10^{-5}	1.0×10^{-6}	6.0×10^{-6}	1.3×10^{-5}	2.0×10^{-6}	3.0×10^{-6}	2.0×10^{-6}	1.4×10^{-5}	
	Ave	7.1×10^{-3}	2.9×10^{-5}	1.0×10^{-4}	7.0×10^{-6}	1.2×10^{-5}	2.0×10^{-6}	3.0×10^{-6}	3.0×10^{-6}	1.4×10^{-5}	
	Standard deviation	2.1×10^{-3}	6.8×10^{-6}	5.0×10^{-7}	2.3×10^{-6}	2.7×10^{-6}	6.7×10^{-7}	9.8×10^{-7}	3.5×10^{-6}	1.7×10^{-6}	
	Skewness	0.54	−0.02	−0.40	4.7×10^{-3}	−0.68	−0.27	−0.57	2.67	0.15	
	Kurtosis	−1.10	0.96	−0.22	−0.35	−0.64	−1.03	−0.53	7.93	−1.30	
Cluster 2	Sum	0.08	4.5×10^{-4}	3.0×10^{-5}	9.0×10^{-5}	1.7×10^{-4}	4.0×10^{-5}	6.0×10^{-5}	8.0×10^{-5}	2.0×10^{-4}	0.086
	Min	3.9×10^{-3}	3.3×10^{-5}	2.0×10^{-6}	6.0×10^{-6}	1.6×10^{-5}	2.3×10^{-6}	3.4×10^{-6}	1.7×10^{-6}	1.5×10^{-5}	
	Max	0.02	1.1×10^{-4}	5.0×10^{-6}	2.4×10^{-5}	2.2×10^{-5}	9.2×10^{-6}	1.3×10^{-5}	3.1×10^{-5}	0.0000308	
	Median	8.5×10^{-3}	5.0×10^{-5}	3.0×10^{-6}	1.0×10^{-5}	2.0×10^{-5}	4.0×10^{-6}	1.0×10^{-5}	5.0×10^{-6}	2.0×10^{-5}	
	Ave	9.0×10^{-3}	5.0×10^{-5}	3.0×10^{-6}	1.0×10^{-5}	2.0×10^{-5}	4.0×10^{-6}	1.0×10^{-5}	1.0×10^{-5}	2.0×10^{-4}	
	Standard deviation	4.7×10^{-3}	2.4×10^{-5}	9.6×10^{-7}	5.5×10^{-6}	2.1×10^{-6}	2.4×10^{-6}	3.2×10^{-6}	9.6×10^{-6}	4.6×10^{-6}	
	Skewness	1.01	2.53	0.39	2.06	0.55	1.55	1.41	1.94	0.78	
	Kurtosis	0.54	6.97	−0.78	4.73	0.28	1.43	0.87	3.84	0.79	
Cluster 3	Sum	0.04	2.7×10^{-4}	1.0×10^{-5}	5.0×10^{-5}	1.0×10^{-4}	3.0×10^{-5}	4.0×10^{-5}	3.0×10^{-5}	1.0×10^{-4}	0.040
	Min	3.5×10^{-3}	3.1×10^{-5}	1.0×10^{-5}	5.0×10^{-6}	1.1×10^{-5}	2.0×10^{-6}	4.0×10^{-6}	2.0×10^{-6}	1.1×10^{-5}	
	Max	7.3×10^{-3}	5.3×10^{-5}	2.0×10^{-6}	9.0×10^{-6}	1.6×10^{-5}	6.0×10^{-6}	7.0×10^{-6}	1.0×10^{-5}	2.3×10^{-5}	
	Median	5.4×10^{-3}	3.7×10^{-5}	1.2×10^{-6}	7.6×10^{-6}	1.5×10^{-5}	4.7×10^{-6}	6.6×10^{-6}	4.4×10^{-6}	1.3×10^{-5}	
	Ave	5.7×10^{-3}	3.9×10^{-5}	1.3×10^{-6}	7.1×10^{-6}	1.4×10^{-5}	4.3×10^{-6}	6.0×10^{-6}	4.6×10^{-6}	1.5×10^{-5}	
	Standard deviation	1.4×10^{-3}	7.5×10^{-6}	1.9×10^{-7}	1.9×10^{-6}	1.7×10^{-6}	1.2×10^{-6}	1.0×10^{-6}	2.5×10^{-6}	4.3×10^{-6}	
	Skewness	−0.20	1.42	0.32	−0.13	−1.30	−0.55	−1.24	1.75	1.47	
	Kurtosis	−1.40	2.29	1.35	−2.47	2.49	−0.50	0.77	3.54	1.82	
Cluster 4	Sum	6.8×10^{-3}	3.8×10^{-5}	3.0×10^{-6}	7.0×10^{-6}	1.1×10^{-5}	5.0×10^{-6}	7.0×10^{-6}	1.5×10^{-5}	1.5×10^{-5}	0.007

Table 16
Composition of clusters and distance from the center of a given cluster (value of activation function).

Elements of clusters 1	Value of the activation function	Elements of clusters 2	Value of the activation function	Elements of clusters 3	Value of the activation function	Elements of clusters 4	Value of the activation function
Belgium	0.636	Bulgaria	0.324	Denmark	0.306	Czech Republic	0.427
Luxembourg	0.480	Estonia	0.250	Germany	0.290	Italy	0.281
Malta	0.870	Greece	0.233	Ireland	0.394	Hungary	0.255
Netherlands	0.537	Spain	0.175	United Kingdom	0.294	Poland	0.663
		France	0.260			Portugal	0.203
		Croatia	0.254			Romania	0.227
		Cyprus	0.735			Slovenia	0.287
		Latvia	0.289			Slovak Republic	0.294
		Lithuania	0.191				
		Austria	0.231				
		Finland	0.385				
		Sweden	0.411				

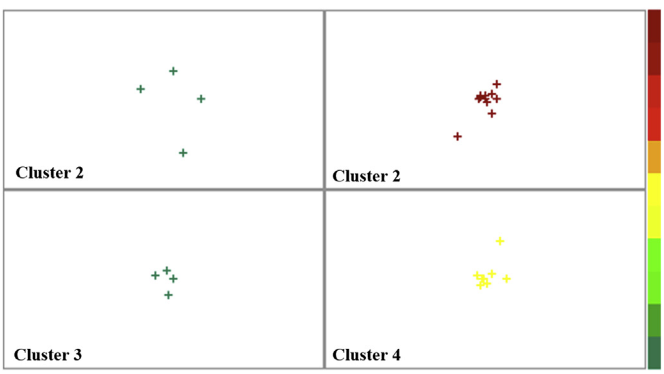

Fig. 14. The Topological map of the Kohonen's neural network grouping the EU countries in terms of the similarities in the volume of emissions of studied greenhouse gases and air pollutants per 1 km^2 of a given country.

lowest emissions in terms of both population and GDP. It is worth noting that in Malta and the Netherlands, forest areas represent the smallest percentage of the country's surface area, which affects the absorption of carbon dioxide (the gas reported to be in largest quantities in this analysis).

The analysis found that as many as 12 EU countries showed similarities in terms of the structure and volume of the emissions of studied substances per area unit. Among them are the countries with the largest surface area among the EU countries, i.e. France, Spain and Sweden. Sweden, in each analysis variant, was found to belong to the countries with the lowest emissions, while France and Spain were found to have the lowest emissions in terms of both GDP and population. Cluster 2 was reported to contain countries where forest areas account for the largest percentage of their surface area. They include Spain, Sweden, Finland, Estonia, Austria and Bulgaria.

4. Discussion

The results of dividing the EU countries into homogeneous clusters (groups) in terms of the structure and level of the emissions of hazardous substances presented in this article indicate that the assessment of these emissions in individual countries is a complex issue. It can also be seen that the analysis conducted only in terms of the absolute values of individual substances failed to fully describe the actual state of this phenomenon. It is therefore reasonable to broaden this analysis with new factors that could create a better understanding of the causes of the current state and help the process of reducing harmful emissions.

For this reason, when examining the emissions of harmful greenhouse gases and air pollutants, the authors decided to take into consideration three important factors, namely the wealthiness of a given country (the GDP value), the number of inhabitants (a demographic factor), and surface area of a given country (geographical factor). Based on this data, it was found that the division of the EU countries into similar groups was significantly different when compared to the absolute values of studied emissions.

It can therefore be concluded that similar EU groups designated on the basis of additional criteria constitute a new look at the process of these emissions, which undoubtedly complements and broadens knowledge in this area.

Thus, it can be claimed that the developed methodology using the Kohonen's neural network and comparing the emissions of harmful substances to the number of inhabitants, the GDP values of individual countries and their surface area made it possible to obtain results that undoubtedly constitute a new approach to the analysis of these substance emissions.

Moreover, the results of the division of the EU countries into homogeneous groups based on the absolute emission of selected substances also brought a crucial value to this analysis.

When studying the total level of greenhouse gas and air pollutant emissions into the atmosphere in 2017, Germany was found to be the infamous leader in the European Union, responsible for about 22.5% of the emissions in question. The second country is the United Kingdom, which accounts for around 11.5% of studied emissions, while France and Italy respectively 9.9% and 9.8%. As far as Poland is concerned, it was reported to be responsible for 9.3% of these emissions. The listed countries together with Spain (about 8% of emissions) were in the same cluster (group) in terms of the level of studied emissions. In total, these countries are responsible for over 70% of these emissions within the EU. Thus, it is clear that they should jointly develop an effective program to decrease the emissions in question. However, this program must take into account both their social effects and economic possibilities. The public acceptance of apparently costly changes may be of key importance to achieve success in reducing these emissions.

Most greenhouse gases and air pollutants in the examined countries come from the energy and transport sectors (Lechon et al., 2009; Lu, 2017). This applies to carbon dioxide, NO_x and non-methane volatile organic compounds emissions.

The emission of carbon dioxide and NO_x is strongly associated with the burning of fossil fuels for the production of electricity and heat, as well as for the supply of cars with fossil fuels (gasoline, oil, CNG, LPG) (Perera, 2018). With regard to NO_x emissions, car transport is particularly dangerous since car exhausts spread in high concentrations at low altitudes in the immediate vicinity of people.

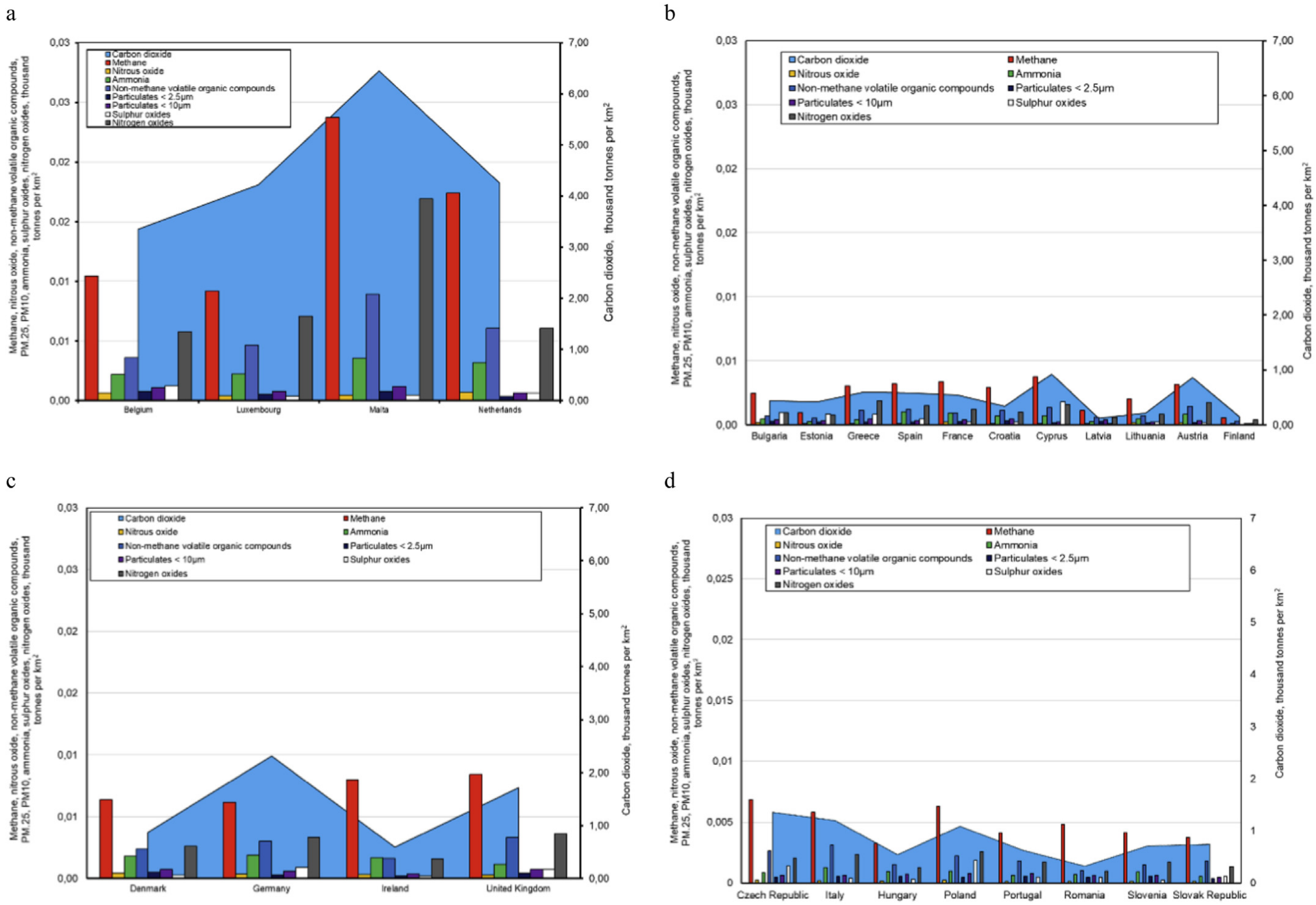

Fig. 15. Emissions of studied substances in relation to 1 km^2 of the surface area of countries in individual clusters (a - cluster 1; b - cluster 2; c - cluster 3; d - cluster 4).

Also, a significant level of methane emissions in these countries can be observed with different sources for each country (Balcombe et al., 2018). The negative impact of methane on the environment is about 21–25 times greater than of carbon dioxide. However, methane is the cleanest source of energy from all fossil fuels (Yang et al., 2018). It has the lowest carbon dioxide emission factor (almost two times lower than in the case of coal).

Only in Poland about 25% of the total methane emissions into the atmosphere currently come from hard coal mining processes. Instead of using this gas for economic purposes, 80% of methane from mines is emitted into the atmosphere (Tutak and Brodny, 2019). In Germany, however, a variety of technological solutions are being implemented to minimize the impact of methane emissions on the surrounding atmosphere. Methane, which is extracted from closed mines, is used, for example, as a fuel in the electricity production process within numerous projects conducted by the Federal States of North Rhine-Westphalia and the Land of Sara (Backhaus, 2017).

On the other hand, there are countries with the lowest levels of greenhouse gas and air pollutant emissions. They include Malta with 0.06% of emissions in the EU, Luxembourg – 0.30%, Lithuania – 0.38%, and Slovenia – 0.39%.

These countries, together with Denmark, Estonia, Croatia, Cyprus, Latvia, Austria, the Slovak Republic, Finland and Sweden, are in the group of countries with the lowest total emissions of studied substances.

Immensely interesting results were obtained when analyzing the emissions in relation to the GDP value of individual countries.

The study of the level of greenhouse gas and air pollutant emissions into the atmosphere expressed in absolute values showed that both Germany and Poland share certain similarities in this respect. They belong to the EU countries with the highest emissions of these substances.

With regard to the economic aspect (GDP value), it was found that Germany emits only twice as many substances dangerous for the environment as Poland, although its economy is up to 7 times larger. Therefore, the emissions of these substances show significant differences in relation to the level of economic development of both countries.

With regard to the GDP value, when determining the impact of the size of the economy on the emissions, only Bulgaria and Estonia were found to be "worse" than Poland in terms of greenhouse gas and air pollutant emissions. Therefore, Poland's situation in this respect is very unfavorable.

The opposite countries include Sweden, Denmark, Ireland, and France. Although Germany emits the most greenhouse gases and air pollutants, it is still below the EU average, which is 0.34 thousand tones per million Euro of GDP for all studied substances. Also, other largest emitters of greenhouse gases and air pollutants within the absolute values below the EU average include Great Britain, France, Italy, and Spain.

The results of dividing the EU countries into homogeneous structures in terms of the level of emissions for each studied substance showed that in many EU countries, the emissions in relation to the size of the economy characterized by the GDP value are

Table 17
Statistical data on the emissions of studied substances per 1 km2 of the area of individual clusters.

		CO_2	CH_4	N_2O	NH_3	NMVOC	PM2.5	PM10	SOx	NOx	Sum
Cluster 1	Sum	18.27	0.06	2.2×10^{-3}	0.01	0.02	2.4×10^{-3}	3.7×10^{-3}	2.7×10^{-3}	0.04	18.41
	Min	3.35	9.2×10^{-3}	4.0×10^{-4}	2.2×10^{-3}	3.6×10^{-3}	3.0×10^{-4}	6.0×10^{-4}	4.0×10^{-4}	5.8×10^{-3}	
	Max	6.44	0.02	7.0×10^{-4}	3.5×10^{-3}	8.9×10^{-3}	8.0×10^{-4}	1.2×10^{-3}	1.2×10^{-3}	0.02	
	Median	4.24	0.01	6.0×10^{-4}	2.7×10^{-3}	5.4×10^{-3}	6.0×10^{-4}	9.0×10^{-4}	$6. \times 10^{-4}$	6.7×10^{-3}	
	Ave	4.57	0.02	6.0×10^{-4}	2.8×10^{-3}	5.8×10^{-3}	6.0×10^{-4}	9.0×10^{-4}	7.0×10^{-4}	9.0×10^{-3}	
	Standard deviation	1.33	6.7×10^{-3}	1.0×10^{-4}	7.0×10^{-4}	2.3×10^{-3}	2.0×10^{-4}	3.0×10^{-4}	4.0×10^{-4}	5.3×10^{-3}	
	Skewness	1.38	0.68	−0.04	0.21	0.94	−0.66	−0.07	1.55	1.94	
	Kurtosis	2.60	−1.93	−4.43	−4.72	0.53	−2.34	−4.15	2.36	3.77	
Cluster 2	Sum	5.25	0.03	1.4×10^{-3}	6.1×10^{-3}	0.01	2.3×10^{-3}	3.7×10^{-3}	5.8×10^{-3}	0.01	5.32
	Min	0.10	4.0×10^{-4}	4.0×10^{-5}	9.0×10^{-5}	2.6×10^{-4}	4.0×10^{-5}	9.0×10^{-5}	4.0×10^{-5}	2.8×10^{-4}	
	Max	0.92	3.7×10^{-3}	2.1×10^{-4}	1.0×10^{-3}	1.4×10^{-3}	3.0×10^{-4}	5.0×10^{-4}	1.8×10^{-3}	1.9×10^{-3}	
	Median	0.43	2.7×10^{-3}	1.0×10^{-4}	4.0×10^{-4}	8.0×10^{-4}	2.0×10^{-4}	3.0×10^{-4}	2.0×10^{-4}	9.0×10^{-4}	
	Ave	0.44	2.2×10^{-3}	1.0×10^{-4}	5.0×10^{-4}	8.0×10^{-4}	2.0×10^{-4}	3.0×10^{-4}	5.0×10^{-4}	1.0×10^{-3}	
	Standard deviation	0.28	1.2×10^{-3}	5.0×10^{-5}	3.1×10^{-4}	4.0×10^{-4}	8.0×10^{-5}	1.0×10^{-4}	5.2×10^{-4}	5.3×10^{-4}	
	Skewness	0.46	−0.47	0.20	0.23	−0.03	−0,53	−0.79	1.58	0.19	
	Kurtosis	−0.68	−1.46	−0.01	−1,18	−1.35	−0.52	−0.53	2.44	−1.12	
Cluster 3	Sum	5.50	0.03	1.4×10^{-3}	6.5×10^{-3}	0.01	1.3×10^{-3}	2.4×10^{-3}	2.0×10^{-3}	0.01	5.56
	Min	0.59	6.2×10^{-3}	3.0×10^{-4}	1.2×10^{-3}	1.1×10^{-3}	2.0×10^{-4}	4.0×10^{-4}	0.0002	1.6×10^{-4}	
	Max	2.32	8.4×10^{-3}	4.0×10^{-4}	1.9×10^{-3}	3.3×10^{-3}	5.0×10^{-4}	7.0×10^{-4}	0.0009	3.6×10^{-3}	
	Median	1.30	7.2×10^{-3}	3.0×10^{-4}	1.7×10^{-3}	2.7×10^{-3}	4.0×10^{-4}	6.0×10^{-4}	5.0×10^{-4}	0.3×10^{-3}	
	Ave	1.37	7.2×10^{-3}	3.0×10^{-4}	1.6×10^{-3}	2.6×10^{-3}	3.0×10^{-4}	6.0×10^{-4}	5.0×10^{-4}	2.8×10^{-3}	
	Standard deviation	0.79	1.1×10^{-3}	1.0×10^{-4}	0.0003	7.0×10^{-4}	0.0001	2.0×10^{-4}	3.0×10^{-4}	9.0×10^{-4}	
	Skewness	0.37	0.09	0.21	−1.62	−0.66	−0.45	−1.13	0.21	−0.85	
	Kurtosis	−2.82	−5.16	0.47	2.85	−1.02	−3.08	0.26	−4.62	−0.46	
Cluster 4	Sum	6.57	0.04	1.3×10^{-3}	6.8×10^{-3}	0.02	4.0×10^{-3}	5.3×10^{-3}	5.7×10^{-3}	0.01	6.66
	Min	0.32	3.2×10^{-3}	1.0×10^{-4}	5.0×10^{-4}	1.0×10^{-3}	4.0×10^{-4}	5.0×10^{-4}	2.0×10^{-4}	1.0×10^{-3}	
	Max	1.35	6.9×10^{-3}	2.0×10^{-4}	1.3×10^{-3}	3.1×10^{-3}	6.0×10^{-4}	8.0×10^{-4}	1.9×10^{-3}	2.6×10^{-3}	
	Median	0.72	4.5×10^{-3}	2.0×10^{-4}	9.0×10^{-4}	1.8×10^{-3}	5.0×10^{-4}	6.0×10^{-4}	5.0×10^{-4}	1.7×10^{-3}	
	Ave	0.82	4.9×10^{-3}	2.0×10^{-4}	9.0×10^{-4}	1.9×10^{-3}	5.0×10^{-4}	7.0×10^{-4}	7.0×10^{-4}	1.8×10^{-3}	
	Standard deviation	0.35	1.3×10^{-3}	1.0×10^{-4}	2.0×10^{-4}	7.0×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	6.0×10^{-4}	6.0×10^{-4}	
	Skewness	0.27	0.40	0.51	0.47	0.53	−1.26	−0.68	1.50	0.16	
	Kurtosis	18.27	0.06	2.2×10^{-3}	0.01	0.02	2.4×10^{-3}	3.7×10^{-3}	2.7×10^{-3}	0.04	

incomparably high. In the case of Poland, the main reason for this is to be found in the energy sector based on conventional energy sources (Gawlik and Mokrzycki, 2019) and in the road transport sector (National Road Safety Programme, 2014).

It is also obvious that the level of emissions of primarily greenhouse gases is the result of dynamic economic growth. High emissions of these gases must therefore be in countries with a high GDP value. At the same time, these countries have resources to limit these emissions, which they should use as soon as possible.

The level of the emissions measured globally is constantly rising and only a few times throughout our history has this constant trend been statistically significantly reversed. This was the case during the Great Depression in 1930 and the second fuel crisis in 1981. CO2 was also emitted on a smaller scale during World War II and the last financial crisis in 2009. It turns out that the current reduction of greenhouse gas emissions has been caused mainly by global economic crises. It will probably be similar in the case of the global economic crisis caused by SARS 2-COVID 19.

According to a political scientist Roger Pielke Jr of the University of Colorado in Boulder, the iron rule of climate policy is as follows: "If the emission reduction program conflicts with the policy supporting economic growth, then pro-growth policy is always the winner of such a clash" (Financial Observer, 2014). It seems that the time is coming to deny this rule at least in the EU countries.

The number of inhabitants is another extremely important factor affecting the similarities between the EU countries in terms of greenhouse gas and air pollutant emissions.

In 2017, countries that emitted the most greenhouse gases and air pollutants per capita were: Luxembourg (18.5 tones), Estonia (15.8 tones), the Netherlands (10.4 tones) and the Czech Republic (10.1 tones). It was reported that the emissions in these countries significantly exceeded the EU average of 7.31 tones for 2017.

Both Luxembourg and Estonia are the countries that, in terms of the level of greenhouse gas and air pollutant emissions expressed in absolute and relative values compared to the GDP value, were reported to have the lowest levels within the EU, yet when considering the number of inhabitants, they turned out to be the largest emitters.

On the other hand, the most favorable rankings include Romania (3.6 tones per capita), Latvia (4.1 tones per capita) and Sweden (4.6 tones per capita). In terms of the absolute emissions, these countries were not in the same cluster.

In the next analysis, the amount of greenhouse gas and air pollutant emissions were compared to the surface area of a given country. It was assumed that the size of a given country is also a factor that should be taken into account, because in many EU countries, it is related to afforestation of their surface area and access to RES. Forests are an important factor in the fight against climate change since they can capture carbon dioxide while reducing its carbon content.

Forest areas represent the largest percentage of the total area of countries such as Finland, Sweden, Slovenia, Latvia, Estonia, Austria, Slovakia, Spain, Portugal, and Bulgaria. The lowest percentage is reported for Malta, the Netherlands and Ireland.

The presented results clearly show that grouping the EU countries and their assessment only through the prism of the level of greenhouse gas and air pollutant emissions as absolute values failed to reflect their specificity or diversity. Taking into account the demographic and economic factors significantly broadens the knowledge in this area.

These disproportions should be considered when setting emission limits. It is obvious that the economic potential of individual countries is very different, and thus their possibilities for economic transformation are also varied.

There are countries which believe that the number of inhabitants should be a deciding factor with regard to, e.g.

greenhouse emission limits. There are proposals which say that since Germany comprises about 15% of the EU population and emits over 22% of all substances included in the analyses, it cannot require of other countries, with a smaller number of inhabitants and less emission, that they take more intensive measures to reduce the emissions in question.

On the other hand, due to the adopted regulations regarding the reduction of greenhouse gas and air pollutant emissions, highly developed countries such as Germany, France or the UK are striving for developing countries to take much more intensive measures to reduce environmentally hazardous substance emissions.

In this context, the results of the analysis presented in this paper should make a significant contribution to the discussion on a future pro-ecological policy in the EU and other countries both in Europe and Worldwide. It is important to adopt a policy accepted by as many countries as possible. It is also crucial that its implementation should not lead to the economic collapse of less prosperous countries or a significant deterioration of living standards in these countries. It should be remembered that the development of the world's most prosperous countries in many cases took place at the expense of destroying the natural environment. Thus, expecting other countries to cover the costs of improving the quality of this environment can be difficult to accept.

What is more, it needs to be emphasized that the diversity of the EU countries in terms of the wealthiness and population size, as well as the structure of emitted pollutants means that the same emission assessment criteria cannot be applied to all of them. The new approach presented in the paper confirms the validity of this thesis.

Additional factors and the use of the Kohonen's neural network enabled a new division of the EU countries into similar groups, taking into account their GDP value and number of inhabitants. According to the authors, these results, combined with the division of the EU countries based on the absolute emission values of studied substances, significantly increase the knowledge of these emissions. At the same time, the presented methodology enables both the analysis and tracking of changes in the scope of the emissions of studied substances and similarities between individual countries also in subsequent years.

As evidenced by the results, a reduction of harmful substance emissions can be observed in the EU countries. For this process to take place even more dynamically, solidary cooperation between these countries is necessary. Without mutual help, it will be very difficult to achieve these goals.

Also, the analysis of changes in the emissions of individual gases and dusts between 2007 and 2017 indicates huge differences for individual EU countries. Despite enormous social pressure, pro-ecological policies and many joint declarations, a large diversity in this issue can be noted. This shows that environmental policies should also be dedicated to similar groups of countries to provide better possibilities of using funds and their control.

All this should lead to the development and implementation of an effective pro-ecological policy, which will take into account the diversity of the European countries and will enable the sustainable development of all these countries.

The application of the self-organizing Kohonen's neural network and the comparison of gas and dust emissions to the GDP value, the number of inhabitants and the area of individual EU countries enabled the acquisition of new knowledge and undoubtedly constitutes a new approach to this subject. Of the many taxonomic methods that could be used for this type of analysis, the Kohonen's network was found to be the most adequate tool guaranteeing independent grouping results. The Kohonen's network can detect connections that would have been neglected if another classification method had been used (e.g. the Ward method).

The designation of similar groups of the EU countries, taking into account additional factors, is a crucial and new achievement and should be taken into consideration when constructing a new pro-ecological policy for the EU countries, including the distribution of funds from the Just Transition Fund.

It is therefore obvious that the developed methodology, the artificial neural network model and the results significantly expanded knowledge in the field of harmful gas and dust emissions in the EU countries. It is clear that these issues are very complex, and for its extensive analysis, it is necessary to use advanced scientific methods. The research allowed the authors to obtain interesting results, which are very valuable from both scientific and utilitarian points of view.

The analyses carried out and the results obtained also indicate future directions of research in the field of emissions of harmful substances. First of all, based on the designated groups of similar countries, an analysis of harmful emissions from selected sectors of the economy of these countries should performed. Sectors that require such analysis are undoubtedly the energy, transport, agriculture and mining industries.

Moreover, the results should enable more effective financing of pro-ecological investments. In order to effectively support the emission reduction process, this financing need to be targeted at sectors and groups of countries. The results presented in the paper show that the large diversity of the EU countries requires a dedicated approach to climate policy.

5. Conclusions and future directions

The conducted analysis clearly showed that in the last 10 years there has been a decrease in greenhouse gas and other air pollutant emissions into the atmosphere by the EU Member States. Undoubtedly, the reason for this is the increase in public awareness and legal regulations adopted to limit the emissions of harmful substances. The countries with high GDP values achieve the best results in reducing emissions of hazardous substances expressed in absolute values. Their prosperity allows them to promote and conduct a very costly policy of limiting emissions of harmful substances. However, it should be remembered that these countries are also the largest emitters of these detrimental compounds. Despite the relative reduction of these emissions, they still rank among the top emitters in terms of the absolute values.

Both the analysis and its results found a large variation in the emissions of harmful substances in the EU countries. These differences are reflected even more by the results of grouping the countries while comparing these emissions to the number of inhabitants and the GDP value.

The large economic and demographic diversity of the EU countries means that many of them cannot afford to introduce changes to limit the emission of harmful substances quickly.

The analyses of grouping countries into similar clusters in the field of gas and dust emissions showed that only 2 of the 28 EU Member States in 2017, for each analysis variant, showed similarity in terms of the structure and volume of these emissions. These countries include Austria and Sweden, which, for each emission variant, were found to have the lowest mean values of studied substances. The remaining countries, when considering emissions per GDP, the number of inhabitants or surface area, showed similarity to slightly different countries. Also, they were found to be neither the largest nor the smallest emitters.

The analysis also found that Germany, France, Italy, and the United Kingdom, being the countries with the highest emissions of studied substances, after taking into account the economic and demographic factors, were reported to belong to the group of countries with the lowest emissions. In turn, for example, Estonia, belonging to the countries with the lowest total emissions, also in relation to the surface area, when taking into account the economic and demographic factor, was found to have the highest emissions. Croatia was found to be among the countries with the lowest emissions for only two variants - once among the countries with the highest emissions and once among countries with the average emissions of studied substances.

These new divisions show that the diversity of the EU countries makes it necessary to take into account many factors when creating and implementing climate policies.

Therefore, the results, especially in terms of designating groups (clusters) of countries with similar structures of the emissions should be used to develop a new policy to decrease them in Europe.

This policy needs to be applied to homogeneous groups instead of individual countries. A large number of countries in Europe with diverse economic and demographic potential, additionally located at various levels of economic development, are not conducive to an effective uniform environmental policy. Closer cooperation between countries in individual clusters (groups) would be more natural in order to reduce emissions of these substances. In this regard, more joint and specific measures should be undertaken to achieve this goal.

In order to significantly improve the quality of the natural environment in the EU countries, it seems necessary to conduct a comprehensive environmental policy targeted at specific groups of countries. It is also necessary to help more affluent countries with less economic potential. Otherwise, there will be more and more differences in the quality of the environment in these countries. On the other hand, the financial burden imposed due to non-compliance with the quality standards of this environment will economically, and thus also socially, deteriorate the potential of these countries. A sustainable development policy in such conditions can be very difficult.

To sum up, the results indicate the need to intensify activities in the field of environmental protection in the EU. A more comprehensive approach to this policy is crucial, taking into account the large diversity of the EU countries.

Cooperation between similar countries included in the homogeneous clusters creates great opportunities to develop joint effective programs, as well as both technical and technological solutions limiting the emission of harmful substances.

The results broaden the knowledge of the emissions of harmful substances by individual EU countries and should become a source of information for people involved in creating pro-ecological policies.

The division of countries into similar clusters should form the basis for further debate on creating strategic guidelines for setting limits for greenhouse gas and air pollutant emissions by the EU countries.

European integration in the field of environmental protection should be understood as joint actions of individual countries, even at the cost of limiting their independence. It should be assumed that for the environment, political borders between countries are not important. Thus, environmental policies must be conducted comprehensively and should be directed at global rather than local goals. It is also significant that other European countries not belonging to the EU join these initiatives.

Based on the results, it can be concluded that further research in the field of environmental protection in the EU countries should include analyses of the impact of individual industries on this environment. This needs to apply to determining the relationship between a given type of pollution and its source industry. Also, it becomes necessary to refer these pollutants to individual countries. Such comprehensive analyses would allow the development of dedicated programs to reduce the emissions of harmful substances for both specific industries and countries. Undoubtedly, the industries that need to be analyzed as soon as possible are energy, transport and agriculture sectors. However, it would also be reasonable to determine the similarities of the EU countries in terms of greenhouse gas and air pollutant emissions, and their energy structure.

Also, the use of the Kohonen's neural network will enable the achievement of study objectives in this respect.

To sum up, the conducted research represents a new approach to the analysis of harmful substance emissions. The developed methodology, using a modern research tool in the form of the Kohonen's network, enabled the authors, through the use of scientific methods, to solve the research problem, which was the lack of connection between the specificity of the EU countries and the emission of harmful substances. This connection was expected to be quantitative, instead just qualitative and, most often, very general.

At the same time, the study opened up new possibilities for conducting analyses in relation to the values characterizing individual countries. As already mentioned, it would be important to refer to individual economic sectors in the context of energy use and generated emissions of, e.g. greenhouse gases. It would also be important to identify changes related to the introduced regulations.

The lack of comprehensive emission assessment results for individual countries in relation to the factors that take into account their diversity can undoubtedly be considered an existing research gap. The problem in this respect was the lack of both the concept and idea how to present the diversity of emissions based on specific data and propose the use of the results. The methodology developed on the basis of additional criteria largely filled this gap and solved the problem. The designation of similar groups of the EU countries for several criteria creates opportunities for their use in implementing new climate ideas. This can be a great opportunity for cooperation and economic growth for countries in the same groups. This, in turn, can translate into business and managerial implications. Cooperation in the field of environmental protection seems to be an ideal opportunity for the development of many economic and social sectors.

Therefore, it can be concluded that the research presented in the paper expanded the knowledge of the emission of harmful substances by the EU countries, and the results provide great opportunities for their practical application by the EU institutions, individual countries and entrepreneurs, who should take advantage of the huge opportunities created by The European Green strategy Deal.

The developed methodology, the research and the results revealed that in order to make a reliable diagnosis of the state of the atmosphere in the EU countries, it is crucial to apply a new scientific approach to this analysis. Undoubtedly, this condition is met by the methodology developed and used in the paper based on the Kohonen's network model. The results significantly expanded knowledge of this issue. At the same time, they provided a lot of new information regarding similarities between very different EU countries. Taking into account demographic, economic and geographical factors has enabled a completely new view on the issue of harmful gas and dust emissions in the EU countries. This, in turn, should result in a modification of the approach to climate policy. This policy should consider the specificities of individual countries and use the similarities between them, based on which new climate strategies can be created and introduced.

CRediT authorship contribution statement

Jarosław Brodny: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing -

original draft, preparation, Writing - review & editing, Visualization, Supervision, Project administration. **Magdalena Tutak:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, preparation, Writing - review & editing, Visualization, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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