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Emissions of Air Pollutants in European Union Countries – Multidimensional Data Analysis

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1. Introduction

Pollution of air with various kinds of compounds is the cause of many diseases. Numerous studies have shown the relationship of the harmful composition of air with the increase in mortality and hospitalization due to respiratory and cardiovascular diseases. These effects were found in both short-term and long-term studies (Dockery et al. 1993, Brunekreef & Holgate 2002, Pope III et al. 2002, Frumkin et al. 2004, Smith & Ezzati 2005, Whitmee et al. 2015). Pollution with nitrogen dioxide and dust is particularly harmful for human health. In turn, the European ecosystem is exposed to the deposition in the soil and the penetration of sulfuric acids and nitrogen compounds into the waters (SO_x, NO_x, NH_3). Forests are used to remove contaminants. This method is especially important in cities where urban vegetation is used for spatial diversification of the urban area (Smith 1974, Gorham 1976, Ulrich & Pankrath 1983, Ulrich 1984, Escobedo & Nowak 2009; Whitmee et al. 2015).

The cause of air pollution is human activity, mainly related to the combustion of fuels. Therefore, industrial plants, households and transport are the biggest emitters of pollution. In each of these activities, the aim is to reduce pollutant emissions. An example is the metallurgical industry, in which stricter standards were introduced, which in turn meant the use of modern technological equipment (Hartman et al. 1997, Mani & Wheeler 1998, Rokicki 2016, 2017, 2018, Cepeda et al. 2017, Cheremisinoff 2018).

The presented dependencies show that the problem of air pollution is crucial for the health of the human population and the quality of natural environment. This article presents the relationship between environmental pollution and the economy in EU countries. The main objective of the paper was to show the level of air pollution and its relation to economic development in the European Union countries. The specific objectives are: to present the differentiation of pollutant emissions in the EU countries and the dynamics of these changes, to determine the relationships and regularities between the level of economic development and the emission of air pollutants in EU countries.

A hypothesis was put forward in the paper, according to which in the EU countries in the years 2005-2016, the regularities between the level of economic development and emission of pollution in line with the environmental Kuznets curve. In the paper authors propose the method which allow to calculate the decrease of emission to the air harmful compounds in years 2005-2016 with the use of created synthetic index. This index was built on the basis of the measures connected to GDA. Index was used to build the ranking of countries with the greatest decrease of those pollutants and also to divide them into groups of countries with the largest/the smallest decrease in air pollution emission.

2. Literature review

According to the World Health Organization (WHO), air pollution caused the deaths of about 3 million people a year, mainly due to non-communicable diseases. In addition, only one in ten people lived in the city in accordance with WHO air quality guidelines. In high-income areas in the Americas, Europe and the Western Pacific, there has been a reduction in air pollution, while in other regions there has been an increase. As a result, global air pollution increased (Stern 2006, Ambient… 2016).

In the world, the problem of air pollution has existed for centuries. In London, the first complaints about smog were recorded in the 13th century. Historically, it is the easiest to reproduce air pollution caused by sulfur dioxide (SO2). Such estimates date back, in most countries, even up to 1850. The development of industry was associated with the consumption of a large amount of sulfur-containing fuels. In Europe, a rapid increase in sulfur pollution was recorded as first, followed closely in North America in the mid-19th century (Brimblecombe 1977). In North America, SO_2 emissions peaked in 1970, in Europe in 1980, and in South America in 1990. Since then, emissions in these regions have shown a downward trend. Industrialization in Latin America, Asia (besides Japan) and Africa began much later. As a result, emissions of air pollutants in Asia and Africa increased (Kuznets 1955, Cohen et al. 2017, Ritchie & Roser 2019).

In the second half of the twentieth century, there was rapid economic development, especially in countries conducting relatively open economic policy. In the 1960s, regulations on pollution in industrial economies were tightened up. Dirty industries have moved to unregulated economies. At the same time, economic growth in these countries resulted in increased regulations, technical knowledge and investment in cleaner production. The scale of pollutant emissions was therefore limited (Mani & Wheeler 1998).

The environmental Kuznets curve assumes a connection between environmental pollution and economic development. According to it, economic development causes an increase in environmental pollution, but only to a certain point, as this impact decreases along with economic development. In other words, environmental pressure is growing faster than income at the early stages of the country's development and slows down in relation to GDP growth with higher income levels (Stern et al. 1996, Ansuategi et al. 1998, Andreoni & Levinson 2001). There are empirical studies confirming this dependence on the example of developed economies (e.g. Apergis & Ozturk 2015, Jebli et al. 2016, Lau et al. 2018), but also studies which not fully confirm that dependencies in developing countries (Al-Mulali et al. 2015, Dasgupta et al. 2002, Harbaugh et al. 2002, Cole 2003, Dinda 2004). Generally, the authors have not determined the level of income from which environmental degradation begins to diminish. In the case of developing countries, economic liberalization, dissemination of low-emission technologies and a new approach to pollution regulation in these countries are of particular importance for environmental protection. It was also found that developing countries deal with environmental issues sometimes by adopting developed country standards with a short delay and sometimes achieving better results than some rich countries (Stern 2004).

3. Materials and methods

All European Union member states were selected for research purposefully as at December 31, 2016 (28 countries). The research period concerned the years 2005-2016. The sources of materials were EUROSTAT data and literature on the subject. For the sake of clarity, the results from the three-year time periods were taken into account. Only these chemical compounds are included (in Mg = 1,000,000 g = ton), which are covered in the EU emission limits, that is sulfur dioxide (SO_2), nitrogen oxides (NO_x), emissions of non-methane volatile organic compounds (NMVOC), ammonia emissions (NH_3) and PM2.5 fraction dust (particulate matter).

For analysis and presentation of materials, one of the methods of multidimensional data analysis - Grade data analysis (GDA) was used. In this method, the so-called overrepresentation maps that illustrate both underrepresentation and overrepresentation of structures describing a given object by comparing them with average values of these structures are of special importance (Kowalczyk et al. 2004). The basis for creating rankings may be the so-called scores, which on the map are the means of ordered rows for individual countries (the height of these rows shows, in the case of drawing for NMVOC, shows the share of individual EU countries in its emissions over the 12 years studied). Determination of these scores for each substance will allow to elaborate an appropriate synthetic index that will allow the creation of a proper ranking for all substances together. In this case, such an indicator may be the average of scores for individual substances. The scores for each substance were calculated and the values of the synthetic index were marked as Q for each country.

The division into groups was based on the division made using the parameter k, where for:

$$R(Q_i) = \max Q_i - \min Q_i = 0{,}6979 \quad \text{and} \quad k = \frac{R(Q_i)}{3} = 0{,}2326$$

particular groups were created in accordance with the following pattern:

Group 1: $Q_i \in [\max Q_i - 3k, \max Q_i - 2k]$ so in our case: $Q_i \in [0.1331, 0.3657]$

Group 2: $Q_i \in [\max Q_i - 2k, \max Q_i - k]$ so in our case: $Q_i \in [0.3657, 0.5983]$

Group 3: $Q_i \in [\max Q_i - k, \max Q_i]$ so in our case: $Q_i \in [0.5983, 0.8310]$

4. Research results

In the years 2005-2016, the level of pollutants emission to air was generally reduced. To illustrate the scale of emission of pollutants, data for 2016 for all European Union countries were used (Figure 1). In terms of volume measured in tons, nitrogen oxides were emitted the most, and not much less non-methane volatile organic compounds. The smallest emission was in the case of PM2,5 particulate matter. The harmfulness of individual compounds differs. There is no doubt, however, that one should strive to reduce emissions of all types of air pollutants.

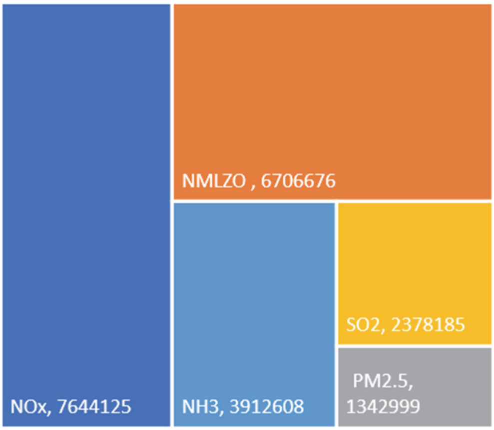

Fig. 1. Emissions of limited air pollutants in EU countries 2016 in tons

As the aim of the paper is to investigate how EU countries dealt with reducing harmful emissions in the air in 2005-2016, Figure 2 presents this problem globally for the entire EU. For this purpose, the overrepresentation map was used, which is a square with sides equal to 1. The column widths represent in this case the structures of emission of harmful substances in total in particular 3-year periods in relation to the entire 12-year period. It can be noticed that these columns are becoming narrower with time, which indicates a gradual decrease in the amount of these substances in the air. The row widths, in turn, show the structure of emissions of individual compounds over the entire 12-year period. It can also be seen that NO_x and NMVOC were emitted the most. Shades of gray on the map depict overrepresentation (darker color) and underrepresentation of structures (brighter color) of emission of particular harmful compounds in relation to the average value. The example of extreme rows shows a clear decrease in the share of SO_2 and an increase in the share of NH_3 in relation to the global emission of harmful dust in subsequent periods. The order in which the individual relationships are shown on the map is not accidental. It strives for such a ranking (in this case) of rows, so as to obtain the highest contrast between the colors and the columns. This goal is accomplished by the GCA (Grade Correspondence Analysis) algorithm, which is the basic tool used to create a clear and structured map. It seeks to such arrangement of rows or columns on the map that maximizes some τ and ρ independence index (Ciok et al. 1995, Kowalczyk et al. 2004)

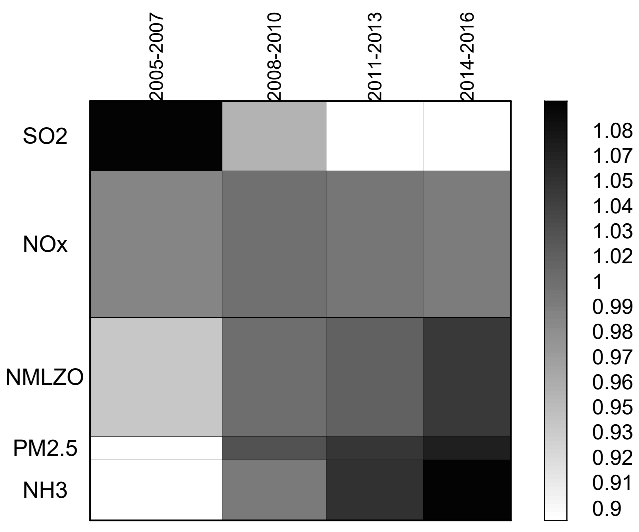

Fig. 2. Overrepresentation map of air pollutants emission in EU in 2005-2016

Since the aim of the paper is to examine the emission of air pollutants in EU countries, similar maps can be made for individual substances in 3-year time periods, ordering countries depending on the degree of decline in dust emissions over time. Such map (for example for NMVOC) is shown in Figure 3. The map is formally a square, but the drawing has been scaled to a rectangle for better transparency.

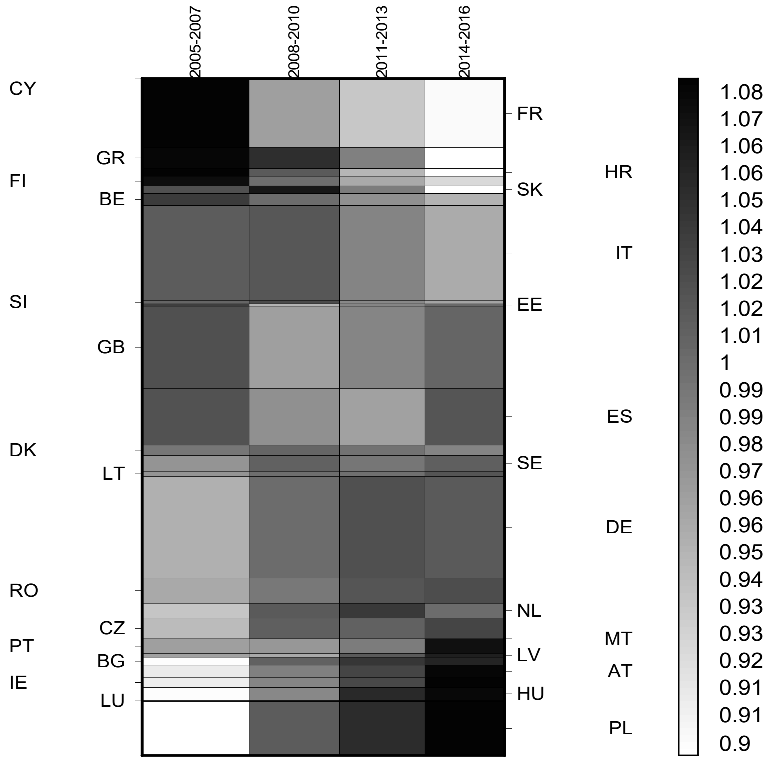

Fig. 3. Overrepresentation map of NMVOC emissions in EU countries in 2005-2016

In general, in the years 2005-2016, the emission of NMVOC dust decreased by 29% across the EU. The reduction of this substance emission (in the sense of structures) in relation to the average for the entire European Union took place in Cyprus, Greece and Croatia (Figure 3). At the bottom of the map are the countries in which the emission of this dust was gradually over-represented in relation to structures for the entire EU. In the case of the NMVOC, Poland occupies a disastrous position. When writing about the position of countries in the non-trivial order, as regards changes in dust emission structures, it is impossible not to refer to the idea of creating appropriate rankings for the dynamics of changes in emissions of individual substances over time. The scores used to calculate synthetic index for each substance and the values of the synthetic index marked as Q for each country are presented in Table 1. In addition, the table sorted the countries in an insufficient manner in relation to Q, thus creating a fairly natural ranking of countries. The top of the ranking is represented by countries in which the emission of harmful substances decreased in terms of structures over time in comparison with emission structures for the entire EU (Greece, Croatia, Belgium). The ranking is closed by countries in which globally the emission of these substances has been over-represented with the passage of time.

Table 1. Scores for harmful substances and synthetic indicator (Q) values for EU countries in 2005-2016 (Source: own research on the basis on GradeStat, country codes: ISO3166-1)

Countries	Scores for air pollutants emission						Group
	NMVOC	NH3	PM2.5	SO_2	NO_x	Q	
GR	0.1176	0.3583	0.0344	0.1339	0.0210	0.1331	Group 1
HR	0.1388	0.0394	0.0108	0.2881	0.3400	0.1634	
BE	0.1788	0.3753	0.0830	0.2998	0.4582	0.2790	
CY	0.0008	0.0913	0.0009	0.6170	0.7561	0.2932	
DK	0.5493	0.1754	0.2711	0.4407	0.0464	0.2966	
ES	0.4997	0.4707	0.4628	0.0528	0.1068	0.3186	
MT	0.8279	0.0001	0.0002	0.4380	0.3439	0.3220	
FI	0.1517	0.1899	0.2407	0.6391	0.6054	0.3653	
FR	0.0519	0.7296	0.1667	0.4731	0.5401	0.3923	Group 2
IT	0.2580	0.2445	0.6740	0.4124	0.3949	0.3968	
PT	0.8388	0.3021	0.3990	0.1718	0.3030	0.4029	
NL	0.7863	0.0174	0.0543	0.6089	0.6314	0.4197	
IE	0.8925	0.6152	0.0673	0.2808	0.4774	0.4666	
LU	0.9197	0.8268	0.0604	0.6324	0.0018	0.4882	
GB	0.3971	0.5660	0.7900	0.5540	0.2259	0.5066	
SI	0.3307	0.3292	0.9409	0.3860	0.7061	0.5386	
SK	0.1644	0.3136	0.7414	0.8550	0.6531	0.5455	
RO	0.7568	0.0674	0.8968	0.3461	0.6905	0.5515	
SE	0.5687	0.3913	0.2559	0.8450	0.7471	0.5616	
EE	0.3347	0.9985	0.0965	0.6258	0.7592	0.5629	
BG	0.8610	0.4045	0.9556	0.2293	0.7312	0.6363	Group 3
CZ	0.8124	0.3409	0.8428	0.8850	0.3250	0.6412	
LT	0.5841	0.3222	0.5115	0.8644	0.9971	0.6559	
PL	0.9603	0.1287	0.5651	0.7458	0.9474	0.6695	
AT	0.8760	0.8175	0.3750	0.6475	0.6675	0.6767	
DE	0.6630	0.9103	0.3301	0.9552	0.8330	0.7383	
LV	0.8523	0.9950	0.2853	0.6140	0.9921	0.7478	
HU	0.9093	0.6397	0.9831	0.9069	0.7160	0.8310	

Table 1 also presents the division of countries into 3 groups. In group 1 there were countries in which the decrease in dust emissions compared to the EU average was the highest, in group 2 – moderate and in group 3 the smallest.

It seemed interesting to verify how the change in GDP values at the same time affects the emission of harmful substances in EU countries. In order to maintain the comparability of the results obtained in the case of GDP, it was done in an analogous manner. A map of overrepresentation of changes in GDP structures in time was created (arranging rows – countries in a similar way as previously) and proper scores were determined. Next, Pearson's linear correlation coefficients were determined between scores determined for GDP and scores for individual dusts and the Q synthetic index. A test was also carried out on the irrelevance of the linear correlation coefficient. The values of individual correlation coefficients together with the t and p-value statistics (at the level of significance of $\alpha = 0.05$) were presented in Table 2.

Table 2. Pearson's correlation coefficients for GDP scores and pollutants emission's scores

	r	**t**	**p-value**
NH_3	0.2176	1.1368	0.2660
NMLZO	0.4646	2.6750	0.0128
PM2.5	0.0941	0.4818	0.6340
SO_2	0.4578	2.6257	0.0143
NO_x	0.4180	2.3463	0.0269
Q	0.5400	3.2719	0.0030

Together with the decreasing in time structures for GDP in comparison with the average values for the EU, the structure for NMVOC, SO_2 and NO_x decreased significantly in time. The relatively high value of the correlation coefficient between GDP scores and Q synthetic factor was mainly influenced by scores for these substances. The value of this coefficient would be significantly higher if it was not for the results obtained for Hungary, where with a low score for GDP, a very high value of the Q coefficient occurred, as shown in Figure 4.

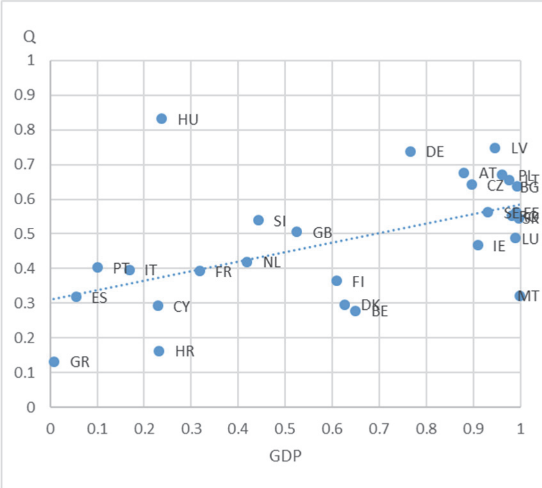

Fig. 4. Wykres rorzutu wskaźnika Q a scory dla GDP

5. Conclusions

1 Air pollution contributes to the development of many diseases and increased mortality in society. The emission of harmful substances increased with the economic development of the world. In individual countries and continents, the stages of economic development were different, therefore the experiences in this area are different. Europe, apart from North America, began to pay attention to the reduction of air pollution as the first one. The environmental Kuznets curve assumes a connection between environmental pollution and economic development. According to it, economic development causes an increase in environmental pollution, but only to a certain point, because this influence then decreases with economic development.

2 The article focuses on harmful compounds that are subject to emission limits (in total there were five such substances). Nitrogen oxides and non-methane volatile organic compounds were the most emitted in the EU. The smallest emission was for PM2,5. In the years 2005-2016, sulfur oxide emissions fell the fastest, while emissions of ammonia and PM2.5 dust increased.

3 In individual EU countries, changes in the emission of harmful substances into the air were different. For example, the decrease in NMVOC dust emission in relation to the EU average was the fastest in Cyprus, Greece and Croatia. There were also countries that were declining from the EU average, such as Poland, Luxembourg and Hungary. At a pace similar to the EU average, emissions of this substance were reduced in Denmark, Sweden and Lithuania.

Taking into account all five pollutants, the ranking of countries meeting the emission obligations against the EU background is presented. Greece, Croatia and Belgium were the best in this area, while Hungary, Latvia and Germany were the worst.

4 A positive relationship was found between the strength of changes in the level of GDP and the emission of air pollutants. In countries where GDP grew slower than the EU average, emissions were lower. In countries with high GDP growth, pollution reduction was very limited. However, there was a reduction of pollutant emissions in all countries. Therefore, the research hypothesis was confirmed, because in the EU countries in the years 2005-2016, the regularities between the level of economic development and emissions were in line with the environmental Kuznets curve. In the economically developed EU countries, despite the pressure of economic development, there was a reduction in air pollution.

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Abstract

The main purpose of the paper was to show the level of air pollution and its relation to economic development in the European Union countries. All European Union member states were selected for research purposefully. The research period concerned the years 2005-2016. Data was obtained from EUROSTAT and from the literature on the subject. For the analysis and presentation of materials, descriptive, tabular, graphical and gradual data analysis methods were used, including overrepresentation maps and Pearson's linear correlation coefficients. The issue of emissions of air pollutants is crucial because harmful substances contribute to the emergence of many diseases and increased mortality of society. The article focuses on harmful compounds that are subject to emission limits, i.e. sulfur dioxide (SO_2), nitrous oxide (NOx), emissions of non-methane volatile organic compounds (NMVOC), ammonia (NH_3) emissions and PM2.5 fraction dust. Nitrogen oxides and non-methane volatile organic compounds were the most emitted in the EU. The smallest emission was for PM2.5. In the years 2005-2016, sulfur oxide emissions decreased the fastest, while emissions of ammonia and PM2.5 dust increased. Taking into account all five pollutants, the ranking of countries meeting the emission obligations against the EU background is presented. Greece, Croatia and Belgium were the best in this area, while Hungary, Latvia and Germany were the worst. A positive relationship was found between the strength of changes in the level of GDP and the emission of air pollutants. In the EU countries, in the years 2005-2016, regularities between the level of economic development and pollution emissions in line with the environmental Kuznets curve were confirmed. In the economically developed EU countries, despite the pressure of economic development, there was a reduction in air pollution.

Keywords:
environmental protection in EU, emissions of air pollutants,
environmental Kuznets curve, grade data analysis, synthetic indicator

Emisja zanieczyszczeń powietrza w krajach Unii Europejskiej – wielowymiarowa analiza danych

Streszczenie

Celem głównym pracy było ukazanie poziomu zanieczyszczenia powietrza i jego związku z rozwojem gospodarczym w krajach Unii Europejskiej. W sposób celowy wybrano do badań wszystkie kraje członkowskie Unii Europejskiej. Okres badań dotyczył lat 2005-2016. Dane pozyskano z EUROSTAT oraz z literatury przedmiotu. Do analizy i prezentacji materiałów zastosowano metody opisową, tabelaryczną, graficzną, gradacyjną analizę danych, w tym mapy nadreprezentacji, współczynniki korelacji liniowej Pearsona. Problematyka emisji zanieczyszczeń powietrza jest kluczowa, gdyż szkodliwe substancje przyczyniają się do powstawania wielu chorób oraz zwiększonej śmiertelności społeczeństwa. W artykule skupiono się na szkodliwych związkach, które podlegają limitom emisji, a więc dwutlenku siarki (SO_2), tlenku azotu (NO_x), emisji niemetanowych lotnych związków organicznych (NMLZO), emisji amoniaku (NH_3) i pyłów frakcji

PM2.5 (PM2.5). W UE najwięcej emitowano tlenków azotu i niemetanowych lotnych związków organicznych. Najmniejsza zaś była emisja pyłów frakcji PM2,5. W latach 2005-2016 najszybciej spadała emisja tlenków siarki, zaś rosła amoniaku i pyłów frakcji PM2,5. Przy uwzględnieniu wszystkich pięciu związków zanieczyszczających powietrze przedstawiono ranking krajów wywiązujących się z obowiązków emisji na tle UE. Najlepiej w tym zakresie radziły sobie Grecja, Chorwacji i Belgia, zaś najgorzej Węgry, Łotwa i Niemcy. Stwierdzono dodatnią zależność między siłą zmian poziomu PKB a emisją zanieczyszczeń powietrza. W krajach UE w latach 2005-2016 potwierdzone zostały prawidłowości między poziomem rozwoju gospodarki i emisją zanieczyszczeń zgodne ze środowiskową krzywą Kuznetsa. W rozwiniętych gospodarczo krajach UE mimo presji rozwoju gospodarczego następowała redukcja zanieczyszczeń powietrza.

Słowa kluczowe:
ochrona środowiska w UE, emisja zanieczyszczeń powietrza,
środowiskowa krzywa Kuznetsa, gradacyjna analiza danych, wskaźnik syntetyczny