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Impact of Road Transport on Air Pollution in EU Countries

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1. Introduction

As a result of transport activities, external effects are created. They can be defined as the various effects of transport processes, the recipients of which are third parties not involved in these transports (Verhoef 1994, Celbis et al. 2014). External effects are the result of imperfections in the market mechanism and lead to discrepancies between private costs and benefits arising from a given business or other activity and social costs and benefits (Fiedor 2002, Rokicki 2016, 2017, Vlahinić Lenz et al. 2018). Transport can have a positive and negative impact on the environment (Dodgson 1973, Rothengatter 1994). The positive impact of transport in historical terms was manifested in the technological and economic development of the world (Gwilliam & Geerlings 1994, Del Bo & Florio 2012, Yu et al. 2013, Jiang et al. 2016). In turn, negative externalities were noticed later (Button 1994).

Nowadays, attention is paid to limiting the unfavorable aspects of transport functioning, such as accidents, environmental pollution, noise, congestion, destruction of nature and landscape (Himanen et al. 2005). The aspect of counteracting the adverse effects of human activity has been particularly important since the beginning of the 21st century. People want to live in a friendly environment and reduce negative externalities (Stetjuha 2017).

Transport is an activity that is usually closely related to economic parameters (Hu & Liu 2010, Alvarez et al. 2016). However, the level of socio-economic development of individual countries may determine the scale of negative externalities of transport. The use of modern vehicles with lower emissions, lower noise levels as well as better road infrastructure contribute to reducing the external effects of transport (Konečný et al. 2016, Mostert & Limbourg 2016). Road transport dominated in most EU countries. It was also a mode of transport generating the most negative externalities (Mostert et al. 2017).

2. Literature review

Air pollutants can be classified as primary or secondary. Road transport mainly emits primary pollution, i.e. going directly to the atmosphere. The main primary air pollutants include particulate matter (PM), black carbon (BC), sulfur oxides (SO_x), nitrogen oxides (NO_x), ammonia (NH_3), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOC). The most important secondary air pollutants are PM, ozone (O_3) and nitrogen dioxide (NO_2) formed in the atmosphere (Peters & Jouvanis 1979, Builtjes & Paine 2003, Daly & Zannetti 2007, Al-Dhurafi et al. 2018, Sówka et al. 2020, Kamińska & Turek 2020).

Total emission of pollutants in the European Union in the years 2000-2017 decreased in relation to the concentration of PM, O_3 and NO_2 in the air, as well as arsenic (As), cadmium (Cd), nickel (Ni), lead (Pb), mercury (Hg). The largest reduction was achieved for SO_x (by 77%), and for NH_3 (9%) (EEA 2019a). Road transport is a major sector contributing to emissions of air pollutants in Europe. The research is based on transport work performed during the transport of people and goods, using cars, motorbikes, buses and coaches (EEA 2018, European Commission 2018). In 2017, road transport in the EU accounted for 39% of emission of NO_x, 18% BC, 19% NH_3, 11% of $PM_{2.5}$ and PM_{10} particles (EEA 2019b, 2019c).

In the road transport sector, emissions of key pollutants (e.g. NO_x) have decreased significantly, despite a gradual increase in the volume of passengers and freight transported. The reason was the initiation of actions at EU level to counteract air pollution from transport, which at the same time enabled the development of the transport sector. An example is regulating emissions by setting emission standards (e.g. Euro 1-6) or setting fuel quality requirements (Dore et al. 2003, Fameli & Assimakopoulos 2015, Dzikuc et al. 2017, Grange et al. 2017, Dzikuc & Dzikuc 2018).

In the years 2000-2017 emissions of air pollutants showed a significant separation from economic activity measured by the value of GDP, which was desirable due to environmental protection and increased productivity. Every euro of GDP generated was associated with ever lower emissions of air pollutants in subsequent years. Success in this area was the result of increased policy regulation and implementation, fuel type swapping, technology improvements and process efficiency, and increased consumption of goods produced in industries outside the EU (Brand 2016, Crippa et al. 2016, Guevara 2016, Rokicki et al. 2018, EEA 2019a, Koszela et al., 2019). EU countries were diverse across the EU in terms of GDP volume, specialization of production, socio-economic characteristics and innovation (Chapman & Meliciani 2017). According to the Kuznets environmental curve, economic development causes an increase in environmental pollution up to a certain point. Later, this impact decreases with economic development, as environmental pressure rises faster than income at early stages of the country's development and slows down relative to GDP growth at higher income levels (Stern et al. 1996, Ansuategi et al. 1998, Andreoni & Levinson 2001) . The dependence presented has been confirmed by the example of economically developed countries (e.g. Apergis & Ozturk 2015, Jebli et al. 2016, Lau et al. 2018), but not fully confirmed in developing countries (e.g. Al-Mulali et al. 2015, Dasgupta et al. 2002, Harbaugh et al. 2002, Cole 2003, Dinda 2004). In developing countries, environmental protection depends on economic liberalization, legal regulations and the use of low-carbon technologies. Developing countries often follow the example of developed countries, adopting their environmental solutions with a short delay (Stern 2004).

Many studies have found a significant relationship between transport infrastructure and economic growth. At the same time, more extensive road infrastructure and urbanization contribute to greater emissions of pollutants into the environment. The level of economic development of the country is also of great importance in this aspect (Achour & Belloumi 2016, Saidi & Hammami 2017, Baloch 2018, Gherghina et al. 2018).

3. Aim, materials and methods

The main purpose of the work is to show the level of air pollution emitted by road transport and its relationship with economic development and transport infrastructure in European Union countries. The specific objectives are: to present the diversity of pollutant emissions from road transport in countries, to show the dynamics of changes in this area, to determine the relationships and regularities between the level of economic development, road infrastructure equipment and air pollution emissions in EU countries. The paper presents a hypothesis according to which in the EU countries in 2006-2017, the regularities between the level of economic development and the emission of pollutants from road transport were confirmed in accordance with the Kuznets environmental curve. All EU Member States were selected for research as of December 31, 2017 (28 countries). The research period concerned the years 2006-2017. The sources of materials were EUROSTAT data, literature on the subject. In the paper, one of the methods of multidimensional data analysis was used to build a ranking of EU countries in terms of emissions of harmful substances into the air. As part of this method, a synthetic indicator constructed based on normalized variables by the method of zeroed unitarisation was used. The determination of this indicator allowed the creation of an appropriate ranking and was the basis for the division of facilities (in this case EU countries) into classes (Kukuła 2014).

The following 14 diagnostic variables treated as stimulants were taken into account in the study (average for the years 2014-2017 for 28 countries):
X_1 – length of roads in km per km^2 of the country,
X_2 – number of vehicles in units per population,
X_3 – NH_3 emissions in tons per road length in km,
X_4 – NH_3 emissions in tons per number of vehicles,
X_5 – NMVOC emissions in tons per road length in km,
X_6 – NMVOC emissions in tons per number of vehicles,
X_7 – $PM_{2.5}$ emissions in tons per road length in km,
X_8 – $PM_{2.5}$ emission in tons per number of vehicles,
X_9 – PM_{10} emission in tons per road length in km,
X_{10} – PM_{10} emission in tons per number of vehicles,
X_{11} – SO emission in tons per road length in km,
X_{12} – SO emission in tons per number of vehicles,
X_{13} – NO emission in tons per road length in km,
X_{14} – NO emission in tons per number of vehicles.

These variables were normalized by the method of zeroed unitarisation. This normalization of variables is very often used in multidimensional data analysis. A detailed description of this method can be found eg. in the paper of K. Kukuła (Kukuła 2014). It's unquestionable advantage is that the normalized variables always take values from the interval [0, 1] and the ranges of variability always have the same width. Then a synthetic index Q was created, being the arithmetic mean of normalized variables. Based on the size of this indicator, a ranking was created of countries that least or poison the environment through road transport, and a division of these countries into 3 groups was made using the parameter k. It was decided to use the parameters k, because this method shows the natural division of variability– in this case, the synthetic variable Q. So taking into account the number of objects and the convenient interpretation of the obtained results, it was set to create 3 groups. Therefore, the range of the Q index in determining the k parameter was divided into 3 according to the formula:

$$k = \frac{R(Q)}{3} \quad \text{where R(Q) is a range} \qquad (1)$$

$$Q_i \in [\max_i Q_i - k, \max_i Q_i] \text{ – Group 1}$$

$$Q_i \in \left[\max_i Q_i - 2k, \max_i Q_i - k\right] \text{ – Group 2}$$

$$Q_i \in [\max_i Q_i - 3k, \max_i Q_i - 2k] \text{ – Group 3}$$

4. Research results

The emission of harmful compounds into the atmosphere and the diversity of its level in the EU countries is associated with various aspects of transport – the number of transporting cars, but also length and quality of roads used by vehicles. Figures 1 and 2 graphically illustrate the average annual rate of change in pollutant emissions (of four compounds: NMVOC, NH_3, $PM_{2.5}$ and PM_{10}) for road transport in the years 2006-2017.

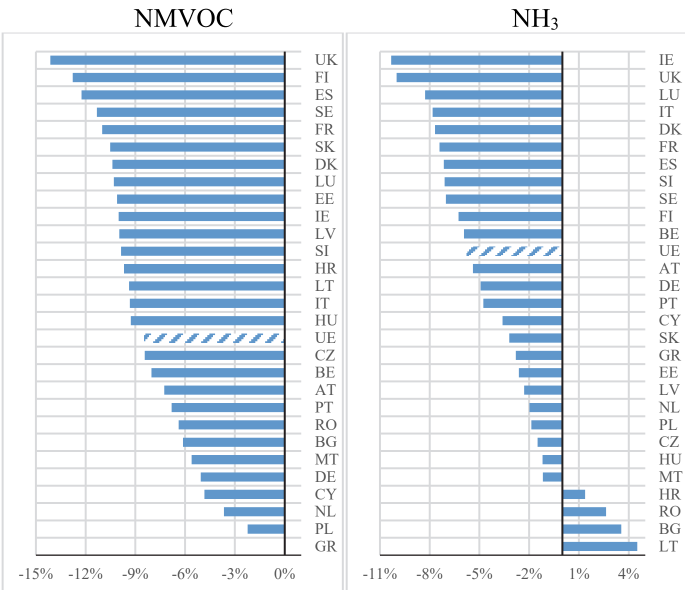

Fig. 1. The average annual rate of change in NMVOC and NH_3 emissions in the European Union countries in the years 2006-2017. Source: author's elaboration based upon EUROSTAT

The average for the entire European Union is marked with a striped bar, the countries with the highest emission reductions of these substances are at the top of the chart, while at the bottom are the countries that have reduced the emission the least or even increased it. For example: the largest NMVOC emitters in the European Union in 2017 were Italy (19.5%), Germany (16.40%), Poland (14.97%) and the rest countries (49.07%), the lowest emissions were recorded in Malta, Luxembourg and Estonia (EUROSTAT). The emission of NMVOC is reduced the fastest by United Kingdom and the Scandinavian countries and Northern Europe (Finland, Estonia, Sweden), while in Poland the pace of change is the slowest (the zero value for NMVOC in Greece is probably due to the lack of data in the Eurostat report). The largest NH_3 emitters in Europe in 2017 were Germany (22.36%), Italy (10.59%), United Kingdom (9.42%), Poland (9.08%), Netherlands (7.96%) (EUROSTAT), although EU directives force EU countries to reduce emissions. Ireland, the United Kingdom and Luxembourg are the countries that lower NH_3 emissions the fastest, while Lithuania, Bulgaria, Romania and Croatia have increased them in the long term. The high average growth rate of NH_3 emissions in Lithuania is caused by a very high relative increase in emissions in 2011 compared to 2010 (91.53%), which influenced the overall assessment of the rate of change in emissions for the whole 12 years, but Lithuania is one of the countries with the lowest emission of this compound.

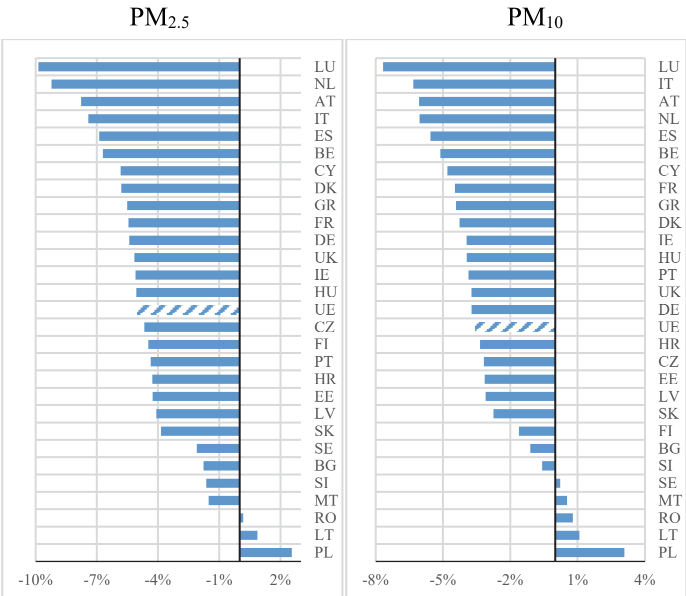

Fig. 2. The average annual rate of change in $PM_{2.5}$ and PM_{10} emissions in European Union countries in 2006-2017. Source: author's elaboration based upon EUROSTAT

The largest emitters of $PM_{2.5}$ in 2017 are: France (17.16%), Germany (13.04%), Italy (11.44%), Poland (10.51%), while of PM_{10} France (13.48%), Germany (12.27%), Italy (9.40%), United Kingdom (8.93%), Poland (8.25%) (EUROSTAT). The average annual increase in dust emissions of $PM_{2.5}$ and PM_{10} type for Poland, Lithuania and Romania is noteworthy, while in the remaining "28" countries a rather downward trend can be observed. In the case of PM_{10} emissions, the average growth rate still applies to Malta and Sweden, but these countries have some of the lowest levels of dust emissions across the Union.

Other pollutants from transport are sulfur oxides and nitrogen oxides for which the highest emissions are recorded by the United Kingdom (21.67%), France (14.20%), Germany (14.12%), Poland (9.18%) – sulfur oxide and the same countries were leaders in nitrogen oxides emissions – gaining total together 63.06% (EUROSTAT). These infamous statements show that Poland is one of the largest transport "polluters" of the environment, and in terms of the rate of change in emissions of both oxides, it is on the last place in the ranking (Fig. 3).

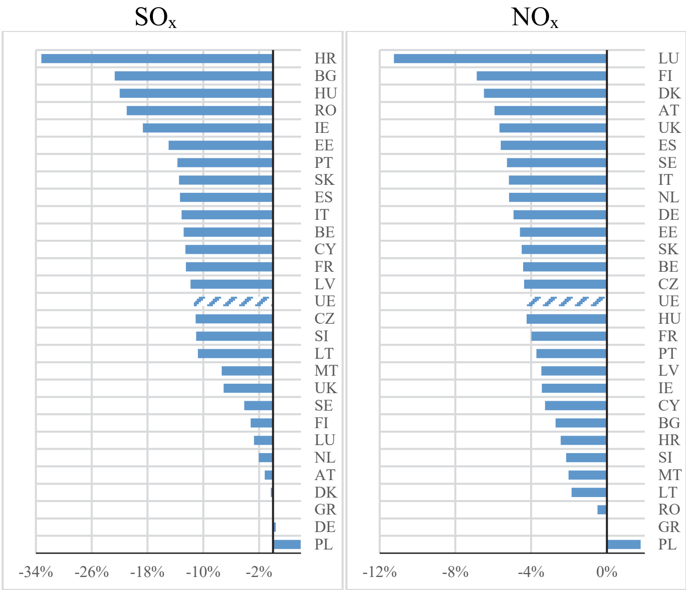

Fig. 3. The average annual rate of changes in sulfur and nitrogen oxides emissions in the European Union in the years 2006-2017. Source: author's elaboration based upon EUROSTAT

The development of road infrastructure and increasing number of vehicles adversely affect the emission of harmful substances. Table 1 summarizes the correlation coefficients for the data from three 4-year time subperiods of the 12-year period studied. The data for which the correlation coefficients were calculated are arithmetic averages for 28 EU countries from 4 years for each of the subperiods. Their high values (from 0.47 to even 0.96-0.98 in the case of $PM_{2.5}$ and PM_{10} and the number of cars and NO_x and the number of cars) confirm this relationship.

Table 1. Correlation coefficients between the average road length and the number of cars and the emission of air pollutants. Source: author's elaboration based upon EUROSTAT

	2014-2017		2010-2013		2006-2009	
	AVH	*LOR*	*AVH*	*LOR*	*AVH*	*LOR*
NH_3	0.90	0.47	0.92	0.52	0.94	0.55
NMLZO	0.89	0.53	0.90	0.60	0.92	0.66
$PM_{2.5}$	0.96	0.83	0.96	0.84	0.96	0.80
PM_{10}	0.94	0.79	0.95	0.82	0.96	0.79
SO_x	0.88	0.71	0.81	0.66	0.59	0.63
NO_x	0.98	0.77	0.98	0.77	0.98	0.75

Legend: LOR – Lenght of the roads – mean value, AVH – All vehicles (except trailers and motorcycles) – the mean value

Figure 4 presents the average rate of change of gross domestic product over the 12 years studied. A certain relationship can be observed here between the average GDP growth rate and the growth rate of pollutant emissions for relatively new EU members such as Poland, Lithuania, Romania and Bulgaria. This conclusion is confirmed by the analysis of the relationship between the average rate of change in consumer spending per capita and the rate of emission of harmful substances – the results are very similar. This correlation lies in the fact that the high growth rate of these two economic indicators is accompanied by a higher growth rate of pollutant emissions.

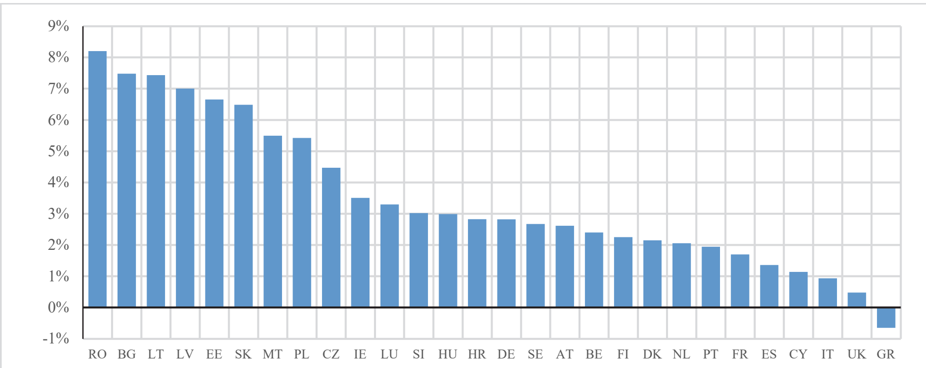

Fig. 4. The average rate of change of Gross Domestic Product in the European Union in the years 2006-2017. Source: author's elaboration based upon EUROSTAT

In this case, it should be noted that the high position of Ireland is largely the result of a large increase in GDP in 2015 compared to 2014. This anomaly was caused by a large injection of foreign capital, which positively affected Ireland's GDP.

Figures 5 and 6 show the relationship between average GDP and average consumption expenditure and the average annual rate of change in emissions of harmful substances into the air in the period 2006-2017. The drawings illustrate the hypothesis of an increase in emissions of transport-related pollution along with the increasing rate of growth of economic development indicators such as GDP or FCE. The graphs in Figures 4 and 5 also clearly show that the increase in emissions depends on the level of economic development. It is easy to notice that countries with a high level of GDP or FCE were characterized by declines in emissions of harmful substances, in contrast to countries that are at a much lower economic level. The bend representing the average rate of change in emissions of harmful substances maintains a clear upward trend along with the decreasing GDP or FCE level, which confirms compliance with Kuznets's environmental theory. The results are somewhat disturbing for NMVOC emissions Greece due to the lack of data on emissions of this dust.

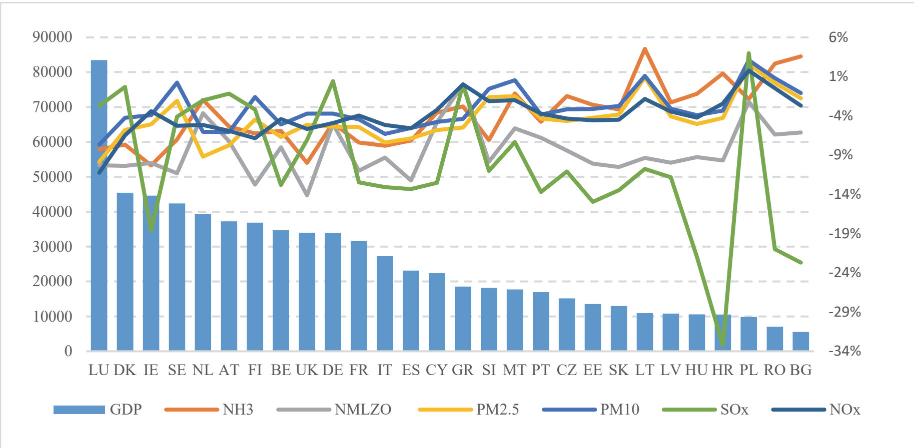

Fig. 5. The average rate of change in Gross Domestic Product and the average annual rate of change in emissions of selected pollutants in the European Union in 2006-2017. Source: author's elaboration based upon EUROSTAT

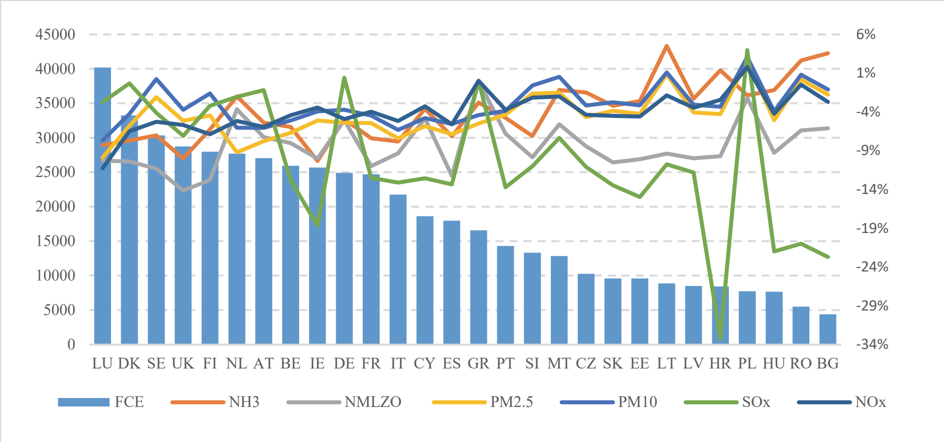

Fig. 6. The average rate of change in consumer spending and the average annual rate of change in emissions of selected pollutants in the European Union in the years 2006-2017. Source: author's elaboration based upon EUROSTAT

One of the aims of the paper was to rank the EU countries in such a way that the emission values of harmful substances from transport were calculated in proportion to the quality of road infrastructure, the area of the country and the number of cars. Table 2 shows the ranking obtained by means of multidimensional data analysis methods, the values of the syn-thetic variable Q and the groups formed.

Table 2. Ranking and grouping of EU countries in terms of the amount of pollutant emissions from transport. Source: author's elaboration based upon EUROSTAT

	2006-2009		2014-2017				2006-2009		2014-2017		
Country	Q	R1	Q	R2	Gr	Country	Q	R1	Q	R2	Gr
GR	0.1056	1	0.1524	1	1	IE	0.2443	20	0.2626	15	1
UK	0.1838	9	0.1581	2	1	DK	0.2462	21	0.2702	16	1
ES	0.1907	13	0.1607	3	1	IT	0.2602	25	0.2908	17	1
SK	0.1882	12	0.1786	4	1	FI	0.2476	22	0.2929	18	1
EE	0.1609	5	0.1794	5	1	HR	0.3630	26	0.2954	19	1
FR	0.1733	8	0.1829	6	1	LT	0.1578	3	0.3013	20	1
CZ	0.1719	7	0.1944	7	1	NL	0.2138	16	0.3054	21	1
RO	0.1590	4	0.2067	8	1	DE	0.2267	17	0.3088	22	1
BE	0.1928	14	0.2092	9	1	SE	0.2527	23	0.3436	23	2
AT	0.1875	11	0.2142	10	1	CY	0.2591	24	0.3521	24	2
LV	0.1412	2	0.2305	11	1	MT	0.2394	18	0.3571	25	2
PL	0.1633	6	0.2467	12	1	BG	0.2427	19	0.3738	26	2
HU	0.1848	10	0.2494	13	1	LU	0.6806	28	0.5816	27	3
SI	0.2126	15	0.2592	14	1	PT	0.5396	27	0.6262	28	3

Table 2 contains the Q indicators and positions that individual countries occupied in the ranking created on the basis of data on diagnostic variables from 2006-2009. The higher the country is in the ranking, the lower the emissions of harmful substances per country, road length and number of cars. You can see the changes that have occurred in terms of the Q factor in the above two 4-year periods. For some countries, these values decreased, e.g. for United Kingdom, Spain, Italy, Denmark, and in some increased (e.g. Lithuania, Latvia, Poland, Bulgaria). The high position of Greece is unreliable in this case due to zero NMVOC emission values. Luxembourg's low position, in turn, does not contradict previous analyzes. The Q index significantly decreased, which means a significant improvement, but still its high value did not allow this country to take a higher place in the ranking, which was built based on relative data. It is a small country with a relatively high population density, dense, as for the area occupied, network of good quality roads and a great geographical location when it comes to the communication route in Western Europe, hence, in terms of the country's surface or road infrastructure, the emission of pollution placed this country in group 3, together with Portugal, with the worst emission parameters.

5. Conclusions

The paper aimed at analyzing emissions of harmful substances from transport that have an adverse effect on the environment in the European Union in the years 2006-2017. Reports and summaries in this regard provide the total annual value of emissions, while the paper attempts to look at the issue of emissions in a way that takes into account other factors related to transport. It is logical that a smaller and non-transit country (such as the island of Malta or Cyprus) will see lower emissions, and large-scale countries with well-developed road infrastructure are not able to have such low emission rates, despite attempts to reduce them. Taking into account the length of roads, the country's area and the number of cars, the dynamics of emission changes (i.e. its reduction in time), the countries can be divided into groups of the largest and smallest emitters, and the results more comprehensively reflect the reality. Thanks to the use of multidimensional data analysis methods and a multifaceted view, the results of calculations better reflect the capabilities of countries in reducing emissions of major harmful substances over the years and allow a different view on the problem of the state of pollution caused by the branch of economy which is transport. It turns out that this approach gives quite surprising results, which in no way undermine other considerations on the dynamics of changes in emitted harmful substances. The example of Luxembourg and its situation, where large emission of harmful substances in a small area is not only the result of a lack of pro-ecological actions on the part of the government, but geopolitical conditions. The ranking created in this way also presents Poland – the main emitter of the harmful substances under study in a more favorable light, although at the same time the country in the 12-year period fell by 6 positions. The ranking pointed to Portugal and Luxembourg as countries with relatively high emissions (group 3), countries with moderate emissions are Bulgaria, Malta, Cyprus and Sweden (group 2).

Analysis of data on the rate of changes in emissions and the volume of GDP in EU countries also indicates compliance with the Kuznets environmental curve – countries with lower economic levels have poorer indicators regarding environmental protection.

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Abstract

The main purpose of the work is to show the level of air pollution emitted by road transport and its relationship with economic development and transport infrastructure in European Union countries. The study presents the diversity in emissions of road transport by countries, shows the dynamics of changes in this area, determines the relationships between the level of economic development, equipping with road infrastructure and emissions of air pollution in EU countries. The research period concerned the years 2006-2017. The sources of data was EUROSTAT database. The ranking built by means of multidimensional data analysis tools indicated Portugal and Luxembourg as countries with relatively high emissions of air pollutants (group 3), countries with moderate emissions are Bulgaria, Malta, Cyprus and Sweden (group 2).

Analysis of data on the rate of change in emissions and the volume of GDP in EU countries also indicates compliance with the Kuznets environmental curve.

Keywords:
road transport, transport infrastructure, air pollution, EU, environmental Kuznets curve, multidimensional data analysis

Wpływ transportu drogowego na zanieczyszczenie powietrza w krajach UE

Streszczenie

Celem głównym pracy było porównanie poziomu zanieczyszczenia powietrza emitowanego przez transport drogowy i jego związku z rozwojem gospodarczym i infrastrukturą transportową w krajach Unii Europejskiej w latach 2006-2017. W pracy przedstawiono zróżnicowanie w emisji zanieczyszczeń przez transport drogowy w krajach UE, ukazano dynamikę zmian w tym zakresie, określono związki i między poziomem rozwoju gospodarczego, wyposażeniem w infrastrukturę drogową, a emisją zanieczyszczeń powietrza. Dane pochodziły z baz i raportów EUROSTAT. Zbudowany za pomocą metod wielowymiarowej analizy danych ranking szeregujący Państwa pod względem emisji związków do atmosfery pochodzących z transportu i uwzględniając infrastrukturę drogową oraz powierzchnię kraju, wskazał na Portugalię i Luksemburg jako kraje o stosunkowo dużej emisji (grupa 3), kraje o umiarkowanej emisji to Bułgaria, Malta, Cypr oraz Szwecja (grupa 2).

Analiza tempa zmian emisji zanieczyszczeń do powietrza oraz wielkości PKB w krajach Unii wskazuje także na zgodność ze środowiskową krzywą Kuznetsa.

Słowa kluczowe:
transport drogowy, infrastruktura transportowa, zanieczyszczenie powietrza, UE, środowiskowa krzywa Kuznetsa, wielowymiarowa analiza danych