Comperative Analysis of Air Quality in European Union Countries as a Result of Innovative Clustering

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Abstract:

Purpose: *The overarching aim of this article is to divide EU countries into classes characterised by different levels of ecology in the field of air quality using factors in the form of emission levels of harmful substances into the atmosphere. The data included in the study concern the year 2017 and come from OECD STAT.*

Approach/Methodology/Design: *The classification of EU countries was carried out using the cluster analysis method as one from data mining methods. The results confirmed the hypothesis that the European Union countries can be divided into three distinct classes according to the criterion of environmental performance in the area of air quality.*

Findings: *In terms of the conditions considered for the international air quality test, concentration 3 was the best, namely Austria, Belgium, Bulgaria, Croatia, Denmark and Finland, Greece, Lithuania, Latvia, Malta,Portugal, Romania, Slovakia, Slovenia, Sweden and Hungary. These are the countries that place the least burden on the atmosphere from harmful factors. The countries belonging to cluster 2, namely Cyprus, the Czech Republic, Estonia, the Netherlands, Ireland and Luxembourg, have also achieved high levels of harmful agents. It should be clearly indicated that the lowest level of emissions of harmful substances into the atmosphere was found in cluster 1, and more precisely in France, Spain, Germany, Poland, Italy, the UK and Wolf.*

Practical Implications: *It turns out that the good practices and recommendations of any sustainable development service do not achieve their purpose in comparison with other EU countries. It seems necessary to tighten the ban policy by imposing high fines on the prohibition of the use of all prohibited objects, devices which have a significant impact on the deterioration of air quality.*

Originality/Value: *There are many reports on the market in the scope discussed above, rich literature compilations. The proposed model may contribute to further development in order to implement the proposed breakdown to reflect actual results in a way that does not seem to hide the worst performing countries.*

Keywords: *Air quality, air pollution, innovation, European Union.*
JEL classification: *O21.*

Paper Type: *Research study.*

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1. Introduction

In the 21st century there is a very dynamic economic development, which is not entirely in all areas is controlled. The lack of control of this phenomenon has a negative impact on societies living in the present time and poses a threat to the quality of life of future generations. One of the most important aspects in the context of human health and life is a very broad area called the environment. Generally speaking, it must be said that this is a place of life and the functioning of societies. One of the elements of the natural environment area are natural resources, which are exploited and polluted under the influence of economic development and, consequently, intensive human activity (Barrera-Roldán and Saldívar-Valdés, 2002).

Sustainable development is very much needed, where it can be pointed out that ecological aspects are a dimension of the broadly understood growth process and socio-economic development (Bansal, 2005; Bossel, 1999; Cash *et al.,* 2003; Costanza and Daly, 1992; Elkington, 1994; Freeman and Ross, 2018). In parallel with the growing economic processes associated with economic development, the concept of sustainable development began to develop - as an antidote to the negative effects of human activity (Heubaum and Biermann, 2015). The concept of sustainable development is a very complex issue. It is precisely because of this complexity that countries that want to achieve its goals have been systematised, dividing them into two: economic, ecological (Balat, 2007; Rowlands *et al.,* 2002).

The concept of sustainable development concerns many areas and as a process it should be implemented in many areas. One of the important aspects of the sustainable development process is the one related to energy production and supply. The energy management process should be carried out in accordance with the principles of the concept of sustainable development (Noja, 2018). To this end, the use of renewable energy sources (RES) should be increased until they represent 100 % of all energy sources. European Union policies and legislation on clean air require significant improvements in air quality the European Union to bring it closer to the quality recommended by the World Health Organisation (Jenkins, 2004). Air pollution and its impact on human health, ecosystems and biodiversity should be further reduced to achieve the long-term objective of not exceeding critical loads and levels. This entails stepping up efforts to achieve full compliance with Union air quality legislation and the definition of strategic objectives and actions beyond 2020 (Gola *et al.,* 2019; Krzyzanowski and Cohen, 2008).

The implementation of European Union environmental policy and law is essential for a healthy environment (Barrera-Roldán and Saldívar-Valdés, 2002). Filling the gap between what has been decided and what has actually been implemented is crucial to ensure good environmental performance of citizens, to maintain a level playing field for economic operators and to create opportunities for social and technological innovation and economic development (Girshick and Rubin, 1952;

Gullino *et al.,* 2008; Wojtaszek and Miciuła, 2019). Studies carried out in 2019 show that the total social costs resulting from the visible gaps in the implementation of environmental policy amount to around EUR 55 billion per year. The biggest challenge for Poland in terms of environmental protection and climate (Cash, 2006).

Nowadays, it is necessary to eliminate low air emissions in single-family buildings. The Polish authorities are expected to include as soon as possible in the government's Low Emissions Programme "Clean Air" additional objectives such as the introduction of RES and the reduction of energy consumption in 2030, including more ambitious measures to reduce carbon dioxide emissions (Ferreira *et al.,* 2013).

For example, according to IRENA and University College Cork Analysis in Poland, in 2030 the share of electricity coming from RES should be 38%, while the current share is about 13%. The CO2 emission index for electricity generation should be lowered from 781 g/kWh to 422 g/kWh in 2030. In 2030 the share of renewable energy in single-family buildings should be 37%. As part of the measures to achieve this, equipment based on renewable energy sources, especially heat pumps, should be used to heat single-family houses.

The European Union has developed comprehensive air quality legislation that sets standards based on health assurance and targets for the reduction of a number of air pollutants (Aerts *et al.,* 2013; Mayer, 1999). Between 1990 and 2016, a decrease in air pollutant emissions (SOx, NOx, NH3) from individual sectors was recorded in Poland - currently their levels do not exceed the applicable national emission ceilings (Guerreiro *et al.,* 2014). Decreases recorded between 1990 and 2014, which were indicated in the previous review of the implementation of environmental policy, continued to be observed between 2014 and 2016: emissions of sulphur oxides (SOx) decreased by 18.63% and ammonia (NH3) by 1.02%. Between 2014 and 2016, volatile organic compound (VOC) emissions increased by 3.04%, fine PM 2.5 by 3.83% and nitrogen oxides (NOx) by 0.05% (Akimoto, 2003; Guerreiro *et al.,* 2014; Moriarty, 1988).

Despite these decreases, further action is needed to meet the emission reduction commitments relative to 2005 levels set out in the new National Emission Ceilings Directive for 2020-2029 and for each subsequent year from 2030 onwards (Jarosz and Faber, 2019). Air quality in Poland continues to raise serious concerns. The European Environment Agency has estimated that in 2015, about 44,500 premature deaths could be due to fine dust concentrations, of which 1,300 deaths were due to ozone concentration 53 and 1,700 to nitrogen dioxide concentration (Petty, 2017).

The review of the literature on the subject and the authors' experience in the studied area was the basis for the determination of the methodological and application gap. A wide spectrum of methods and procedures for measuring the quality of activities within the concept of sustainable development was not found in scientific studies, which undoubtedly constitutes a methodological gap. In the literature there are also

not many ready-made solutions for bodies on different scales, i.e. communities, governmental institutions or self-government institutions that give the possibility to measure, assess the degree of achievement of objectives or compare this degree within the concept of sustainable development, which constitutes an application gap. The observed research gaps were the basis for the authors to formulate the research problem as a question: Are the countries of the European Union, when implementing the objectives of the concept of ecological sustainability, different in the area of air quality? The following four hypotheses were put forward in order to examine this research gap.

The first (H1) indicates that the countries of the European Union in terms of ecological level in terms of air quality are divided into 3 classes. The second class (H2) shows that the level of emissions of harmful substances such as sulphur and nitrogen oxides is a factor which classifies the European Union countries well in terms of the level of ecology in terms of air purity. The third (H3) suggests that emissions of carbon monoxide and non-methane volatile compounds differentiate European Union countries well in terms of air quality. The last (H4) suggests that greenhouse gas emissions are an important factor in classifying EU countries in terms of air quality. Suggesting the basis for answering the question formulated in the research problem, a test sample has been selected, pointing to all European Union countries on data on emissions of harmful substances for analysis.

The overriding aim of this article is to divide the European Union countries into classes characterized by different levels of ecology in terms of air quality using factors in the form of levels of emissions of harmful substances into the atmosphere.

2.   The Objectives of Sustainable Development in Terms of Air Quality

The measures in the aspect of sustainable development indicate the fulfilment of the specific objective 11.6, which states that "*by 2030, reduce the negative environmental impact of the city, paying particular attention to air quality and management of municipal waste and other pollutants*" (Baklanov *et al.*, 2016).

In Poland, about 44,000 people die every year due to high concentrations of dust having a negative impact on air quality (European Commission data) , in the whole of Europe as much as 80% of people living in cities are exposed to high concentrations of particulate matter which significantly exceed WHO standards (Heubaum and Biermann, 2015; Isner *et al.,* 1995; Moriarty, 1988) .

Improving air quality is a specific objective under UN Sustainable Development Objective 11 - Sustainable cities and communities. Since it is estimated that by 2050 the proportion of the world's urban population will increase from about half of the population to 66% - that is why it is so important to consider and sustainable development of cities, which act as economic, social, political and cultural centres. WHO estimates indicate that in Poland, even 45 thousand people die every year due

to diseases associated with high air pollution emissions. This is more than 15 times more than the number of fatal victims of road accidents in Poland, which in 2015 was 2 938. The European Environment Agency indicates that air quality continues to be a very important issue in the sphere of public health, economy and environment (Heubaum and Biermann, 2015).

In the European Union, the costs of diseases caused by air pollutants are estimated to be around 940 billion euros per year. In Warsaw alone, it is estimated that the total health costs of air pollutants are the total health costs of diseases caused by air pollution are not only medical expenses. they are also the costs of employers resulting from the absence of employees, public spending on disability benefits or a smaller increase in PKB. WHO experts estimate that due to air pollution the average life expectancy of a European citizen is reduced by almost 9 months. Polluted air is a public health issue which should be pointed out in the perspective of social inequality. There are significant differences in the state of health, depending on social and economic conditions, level of education or place of residence (ecological conditions). These differences reach even several years (measured in terms of life expectancy). Among malignant neoplasms, the greatest life threat to the inhabitants of Warsaw, as well as to all cities and Poland, is definitely the tracheal, bronchial and lung cancer. In the period 2009-2011, as in previous years, a malignant tumour of the trachea, bronchi and lung was by far the greatest threat to life for the inhabitants of Poland.

Air pollution, such as e.g. dust, carbon monoxide, nitric oxides, polycyclic aromatic hydrocarbons and heavy metals, negatively affects the quality of life, may cause respiratory, circulatory and nervous system diseases, including adult asthma, with prolonged exposure, increase the risk of cancer. Dusts are substances which, due to their small size, penetrate deep into the respiratory system, transporting there hazardous chemicals that stick to the surface of the dust or form the dust it self (Lund and Salgi, 2009). Substances carried by particulate matter, such as polycyclic aromatic hydrocarbons and heavy metals, tend to accumulate in the body. the longer a person is exposed to breathing polluted air, the more harmful substances have penetrated his or her body and the greater the risk of diseases caused by these substances. benzo(a)pyrene is one of the most toxic air pollutants and is highly carcinogenic, and also mutagenic. It accumulates in the body, penetrating mainly through the lungs together with dusts, damaging adrenals, liver, immune and circulatory systems and influencing the occurrence of fertility disorders (Wilson, 2007).

In turn, the impact of air pollutants on vegetation indicates that human activities pose a number of threats to the structure and functioning of these ecosystems and thus to the natural diversity of plant and animal species (Moriarty, 1988). One of the main threats in recent years is the increase in air pollution by nitrogen. Most plant species in these habitats are adapted to nutrient-poor conditions and can only be successfully cultivated on soils with low nitrogen levels (Leili *et al.,* 2008; Yu *et al.,*

2012). Nitrogen is the only nutrient whose circulation through the ecosystem is almost exclusively regulated by biological processes. To establish reliable critical loads of nitrogen, the impact of nitrogen on these ecosystem processes needs to be understood (Yu *et al.,* 2012). The impact of increased nitrogen deposition on biological systems varies, but the most important are: short-term direct impacts of nitrogen gases and aerosols on individual species; impacts on soil; increased susceptibility to secondary stressors; (Akimoto, 2003) and changes in competitive relationships between species resulting in biodiversity loss (Clini *et al.,* 2008).

Measures that could significantly improve air quality are to reduce the negative environmental impact of urban dwellers, to ensure access to safe, affordable, easily accessible and sustainable transport systems and to improve road safety and ensure universal access to safe, inclusive and open green public spaces (Bishoi *et al.,* 2009; Dzierzanowski *et al.,* 2011).

3. Materials and Methods

The aim of the study was to classify the European Union countries in terms of their overall environmental sustainability of air quality. A group of variables (ecological factors) was selected for the study, showing the level of annual emission of harmful substances such as: sulphur oxide, nitrogen oxide, carbon monoxide, non-methane volatile organic compounds and greenhouse gases. The data included in the study concern the year 2017 and come from the OECD STAT.

The classification of European Union countries has been carried out using the cluster analysis method. Cluster analysis is one of the methods of data mining. This method deals with the identification and grouping of objects characterized by similarity in such a way that in groups the objects are as similar as possible to each other in terms of a particular feature and at the same time as different as possible from in the other groups distance. It should also be remembered that cluster analysis is not a statistical test, but a set of algorithms that group studied objects into clusters (clusters). When creating clusters, measures of distance between the studied objects are used. Different distance measures are used: Euclidean distance, Euclidean distance square, Chekbyszew distance or urban distance (Dörre *et al.,* 1999; Ward and Hook, 1963).

Table 1. *Ecological variables (factors) relating to air quality included in the study.*

Variable designation	Variable name
X_1	emission of sulphur oxides in 1,000 tonnes
X_2	nitrogen oxide emissions in 1,000 tonnes
X_3	carbon monoxide emissions in 1,000 tonnes
X_4	emissions of non-methane volatile organic compounds in 1,000 tonnes.
X_5	greenhouse gas emissions per capita in tonnes of CO2 equivalent

Source: *Own study.*

Clusters in cluster analysis can be searched for in two ways: hierarchically and non-hierarchically. The hierarchical methods consist in creating clusters using an iterative procedure. The hierarchical method includes an agglomeration algorithm. In non-hierarchical methods, the researcher must assume in advance how many clusters he wants to divide the examined set of objects. These methods include grouping by the k-average method. Cluster analysis as a research method has long been the subject of interest of researchers from many scientific disciplines, published a compilation of many cases of cluster analysis and the results obtained.

The selection of appropriate variables on the basis of which the objects will be divided is very important in cluster analysis from the point of view of reliability of the results obtained. On the basis of the literature on the subject and knowledge and experience on the examined phenomenon, it is necessary to make a careful selection of variables that describe well the analyzed lens in the scope of the examined phenomenon and they differentiate them well.

Five variables representing the level of air pollution by specific harmful substances have been selected for the study to address a research problem defined in the paper (Table 3). In this study, cluster analysis makes it possible to identify countries that have similarities in terms of variables representing air pollution levels of the harmful substances included in the study. Unlike other methods of multidimensional statistical analysis, cluster analysis is not very restrictive. It is not required that the variables (factors) that will be used for the division of objects had a normal distribution, which is very convenient for researchers.

A very important assumption in cluster analysis is that the sample of the examined objects should be a representative sample, i.e. random and sufficiently numerous. The point is that the conclusions obtained from the study can be generalised to the entire population. Lack of representativeness may lead to distortion of cluster structure. In the case of a study conducted for the purposes of the research problem defined in this article, there is no problem of sample representativeness due to the fact, that all European Union countries were taken into account, i.e. the whole population was surveyed.

4. Results

In the first stage of cluster analysis, the data collected for five variables and all countries were standardised. Cluster analysis was carried out using a non-hierarchical method k - medium. Due to the first research hypothesis put forward by the authors of the paper, that due to the level of ecology in the field of air quality can be divided into three separate groups, the initial number of clusters was taken as three. Initial centres were selected using the option of distance sorting and selection of observations at a fixed interval.

After the analysis of clusters in ten iterations, European Union countries were divided into three clusters. This means that the assumptions made by the authors in the first hypothesis were confirmed. European Union countries are divided into three separate groups taking into account the level of ecology in terms of air quality. The allocation of countries to individual clusters is presented in Table 4.

Table 2. *Division of objects into clusters and distances of each object from the centre of concentration.*

Focus 1		Focus 2		Focus 3	
Facilities	Distances	Facilities	Distances	Facilities	Distances
France	0,582771	Cyprus	0,423031	Austria	0,310386
Spain	0,572488	Czech Repub	0,496936	Belgium	0,382932
Germany	0,790901	Estonia	0,289671	Bulgaria	0,324290
Polska	1,233086	Netherlands	0,446085	Denmark	0,286860
Great Brit	0,476425	Ireland	0,171803	Denmark	0,170855
Italy	0,625160	Luxembourg	0,816151	Finland	0,361078
				Greece	0,391760
				Lithuania	0,144120
				Latvia	0,280412
				Malta	0,393768
				Portugal	0,178282
				Romania	0,425375
				Slovakia	0,105318
				Slovenia	0,204785
				Sweden	0,335404
				Hungary	0,207214

Source: *Own study.*

At this point it is worth noting that each of the variables on the basis of which the division of countries into three clusters was made should relate to the amount of emissions of harmful substances into the atmosphere. In the aspect of the research problem considered in the paper concerning the level of ecology in countries in the area of air quality, the higher values of each of the five variables indicate a lower level of ecology in terms of air quality. Table 3 presents the average values of all variables for individual clusters.

Table 3. *Average values of each dimension within clusters.*

Variable	Focus 1	Focus 2	Focus 3
X_1	1,416	-0,392	-0,384
X_2	1,790	-0,519	-0,476
X_3	1,742	-0,440	-0,488
X_4	1,774	-0,429	-0,504
X_5	-0,192	1,460	-0,475

Source: *Own study.*

Analysing these data in the context of the above statement, it is not difficult to conclude that the countries with the worst air quality from the point of view of the five factors included in the study were in the first cluster. The second and third focus is clearly different from the first focus. Countries included in concentrations two and three clearly dominate in terms of air quality levels over countries in concentration 1. Although air quality levels in countries in concentration two and three are very similar, something has led to them being divided into two distinct concentrations. The fifth variable, the factor of greenhouse gas emissions per capita, decided to separate the two concentrations. The value of variable five for the second cluster is at the highest level of the three groups of countries. This means that the countries of the second group of countries in terms of GHG emissions per capita, they are the worst in comparison with countries from other clusters. This conclusion is the basis for the H4 hypothesis, that the level of greenhouse gas emissions has a significant impact on the differentiation of countries in terms of air quality.
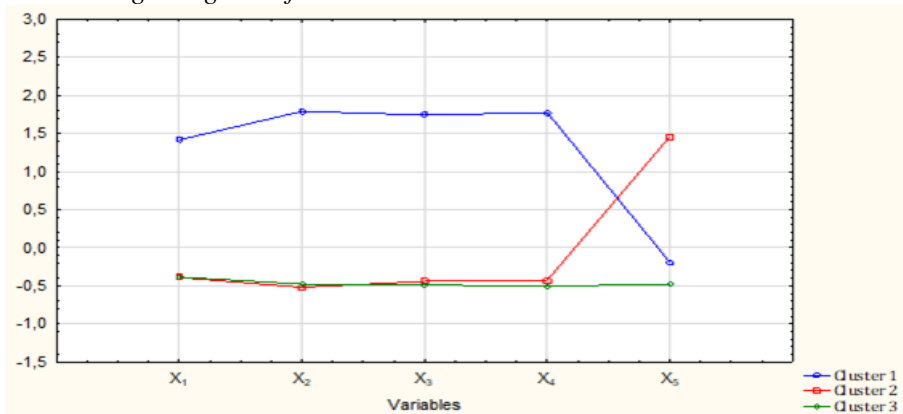
Table 4. *Results of variance analysis.*

Variable	Between SS	df	Internal. SS	df	F	p_v
X_1	15,32607	2	11,67393	25	16,4106	0,000028
X_2	24,49009	2	2,50991	25	121,9667	0,000000
X_3	23,18050	2	3,81950	25	75,8624	0,000000
X_4	24,08134	2	2,91866	25	103,1354	0,000000
X_5	16,64833	2	10,35167	25	20,1035	0,000006

Source: *Own study.*

An additional graphical confirmation of the rightness of the division of countries into three groups, and thus the adoption of the H0 hypothesis, taking into account the level of ecology in terms of air quality, is the graph of average values of individual variables in the three clusters (Figure 1).

Figure 1. *Average diagram of each dimension within each concentration.*

Source: Own study.

Table 4 presents the results of the analysis of variance, which was carried out in order to statistically confirm the validity of the obtained classification. Variability of factors within clusters was compared with variability between clusters. The obtained pv results, which are lower than 0.01 for all five variables, confirm the validity of the obtained division into three clusters. Additionally, taking into account the value of statistics F and pv values, it can be seen that the X_2 variable, i.e. the level of nitric oxide emission, was the dominant criterion determining the affiliation to clusters. This conclusion at the same time gives grounds for the H_2 hypothesis. In the course of the conducted research, an innovative division into three clusters was made.

Figure 2. *Objectives of Sustainable development*
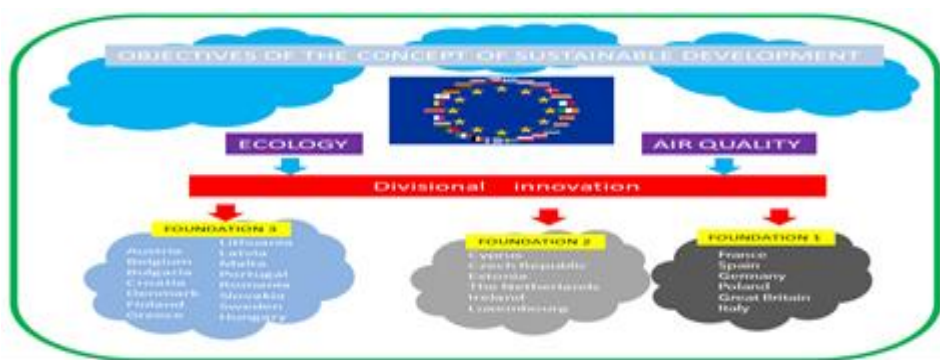
Source: *Own study based on conducted statistical research.*

The above model is an innovative division into three clusters in terms of activities for air quality within the implementation of the concept of sustainable development in this area. The division into three groups of similar clusters may suggest the introduction of motivational actions, which will be classified as less harmful to the atmosphere. The countries belonging to the worst group will be able to model themselves on those belonging to the better group. In order to care for our common good and unsatisfactory results in terms of air pollution, there is a need to categorise and introduce additional taxes for those countries that are among the worst. Another innovation is the use of cluster analysis to explore data (Figure 2).

5. Conclusions

The results of the analysis of clusters for all European Union countries on data on emissions of harmful substances are the basis for answering the question formulated in the research problem. By answering them, we find that the European Union countries, in pursuing the objectives of a complex concept of sustainable development in the field of air quality, are very diverse. This main conclusion is confirmed by the identification of clearly differentiated groups of countries on the basis of five factors concerning the level of emissions of harmful substances into the atmosphere.

The three clusters of countries identified in the study are characterised by different levels of factors reflecting the level of quality of the effects of activities related to the objectives of the sustainable development concept in the area of air quality. The third concentration was the best in this criterion. For this cluster, the average values of all five factors in the study are the lowest, which means that the countries belonging to this cluster have the least polluted air with the harmful substances described in the five factors. The third cluster includes countries: Austria, Belgium, Bulgaria, Croatia, Denmark, Finland, Greece, Hungary, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia, Slovenia and Sweden. Due to the quality criterion of the effects related to air cleanliness measures, the second group was ranked second.

For this cluster, the average values of the first four factors representing the degree of air pollution by certain substances are comparatively low as for the third cluster. The average value of the fifth factor representing GHG emissions is significantly higher than that of the third group, which in the general classification places the second group behind the third group. The second group includes Cyprus, Czech Republic, Estonia, the Netherlands, Ireland and Luxembourg. In the last place, the first cluster was classified. The average value of the first four factors clearly exceeds the values of these factors in the third and second cluster. Only the average value of the fifth factor representing the level of greenhouse gas emissions is lower than in the second cluster. Therefore, it can be said that the countries belonging to cluster one, that is: France, Spain, Germany, Poland and Italy, fall the worst in comparison with the other European Union countries in terms of the quality of the effects of actions for the improvement of air quality under the implementation of the sustainable development concept in this area.

The results obtained confirmed the statement formulated by the authors of the paper in the hypothesis H1 that European Union countries according to the criterion of the ecological level in the area of air quality can be divided into into three separate classes. In addition, a clear division of companies into three groups is essential to confirm the H2 - H4 hypotheses that the five variables on harmful emissions selected for the study were well chosen factors differentiating countries into three distinct groups. To sum up the final conclusions, it can be clearly stated that the overarching goal of the work has been achieved.

6. Recommendationss

Air protection is a European and global problem, a problem that will affect future generations. That is why it is so important to start fighting as early as possible not only for good law and its enforcement, but also for the real importance of the problem, including the sources of air pollution, to be made aware of its tragic consequences. Improvement of air quality cannot be achieved in a short period of time, nor through individual actions. They need to be multi-track, comprehensive and consistent in the long term. Air protection is a national task.

Many years of air quality tests in the countries of the European Union show that the air quality standards are exceeded, especially with respect to fine dusts PM10 and PM2,5 and benzo(a)pyrene contained in this dust. These exceedances are primarily caused by the emission of dusts into the atmosphere from the municipal and commercial sector, which is primarily a consequence of burning solid fuels in high-emission furnaces. Emissions from transport, especially road transport, and industrial emissions are an important source of fine dust, which locally can be an important source of pollution together with professional energy, which affects dust concentrations.

It appears that the good practices and recommendations of all sustainability services do not achieve their objective compared to other EU countries. It seems necessary to tighten up the ban policy by imposing high fines on the use of all prohibited objects, equipment with a significant impact on air quality. We should all take care of the atmosphere, but first of all we should refer to the worst clusters, those that emit the most harmful substances into the atmosphere, namely France, Spain, Nicmcy, Poland, the UK and Italy.

The division into three groups of similar clusters may suggest the introduction of motivational. measures to be classified as less harmful to the atmosphere.
The countries in the worst group will be able to model on the countries in the better group.

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