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Original Research

Air Quality Analysis in the European Union

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Abstract

Environmental quality is a characteristic inherent to all ecosystems, and so knowledge of the indicators that define it, within those of sustainability as a whole, is of vital importance. In particular, environmental analysis of any area should include information on air quality together with data on water, soil, natural resources, and human beings. The distribution of individuals and their impact on the environment varies enormously among countries. This paper presents a statistical analysis of the environmental impact recorded in 27 countries of the European Union, taking into account variables relating to the volume of pollutants emitted to the atmosphere, freshwater abstraction, and the population density in each country. A hierarchical cluster analysis has allowed us to establish groups of countries of similar behavior within the considered variables. Countries with anomalous records (above the EU average) have been detected.

Keywords: environmental pollution, human factor, statistical analysis, European Union

Introduction

The European Union (EU) is composed of 28 countries with an estimated population of more than 500 million inhabitants, and covers more than 4 million km^2. Of these countries, 17 share a common currency within the Euro Zone, while 11 retain their respective currencies. In addition, a few very small countries, such as the Vatican, do not belong to the EU but have adopted the Euro. At present, five countries (Macedonia, Iceland, Montenegro, Serbia, and Turkey) are official candidates for EU membership.

In 1973 the European Commission drafted the first Environment Action Programme, and 30 years later the EU remained committed to the protection of its environment. Legislation controlling gas emissions has led to significant improvements in air quality. In July 2002 the sixth Environmental Action Programme was approved [1] and a 10-year framework was established for community action on the environment. This was adopted by the European Parliament and remained in force until mid-2012. In November 2010, the seventh Environmental Action Programme [2] replaced the former edition, and representatives from the commission, national governments, the European Parliament, and civil society organizations discussed the policies needed to prevent environmental degradation within the EU and the rest of the world. A United Nations report [3] describes the

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environmental impacts on the Earth resulting from human consumption and production in relation to key products and materials.

Within the European Union, the impact of climate change varies among its member countries; the highest risk areas are in the south (in the Mediterranean basin) while air pollution is much less severe in Scandinavia. Despite these differences in air quality, all EU countries are making great efforts to reduce their emissions from industry, vehicles, power plants, and domestic and agricultural sources [4].

Of the pollutant gases, CO_2 is of primary concern. It traps heat, giving rise to the greenhouse effect, and is classified as the gas producing the most impact on air quality in all regions [5]. Its concentration in the air is due to the burning of fossil fuels and to the disappearance of forests and woodland [6]. Another contaminant is sulphur oxide, which as SO_2 or SO_3 is partially responsible for acid rain and is formed, among other causes, by the combustion of coal and oil, by metalworking, and by volcanic activity. Oxides of nitrogen take the form of nitric oxide, nitrogen dioxide, or nitrous oxide. The first two influence the destruction of the ozone layer and are also involved in acid rain, and are largely caused by vehicle emissions.

Ammonia is another primary pollutant containing nitrogen, although it normally provokes low levels of emissions to the atmosphere. Of the volatile organic compounds, the most abundant is methane, which has a major influence on the greenhouse effect and is emitted into the atmosphere from agricultural and livestock activities, waste treatment, etc. Other volatile organic compounds or hydrocarbons play a significant role in the reactions that cause photochemical smog, and are produced mainly by natural processes.

Several studies have analyzed different types of air pollution in relation to persistent organic pollutants [7] and the effects of economic growth on gas emissions [8]. In the present paper, we analyze the spatial behaviour of the levels of emissions within the European Union, using a geographic information system [9], as has been done in earlier studies involving different spatial areas, usually in urban or metropolitan areas [10-11]. An important consideration is that the great size of the study area – the entire EU – complicates both data collection and the management of the variables to be analyzed.

Material and Methods

For the statistical analysis addressed in this study[1] we selected a series of variables that influence air quality. First we considered those related to the emissions of polluting gases such as sulphur oxides, nitrogen oxides, ammonia, and non-methane volatile organic compounds [12]. In addition, we took into consideration the population of each area, as this factor is a determinant of the level of contamination caused by human action. The population size is a strong indicator of the pollution resulting from development in industry, agriculture, transport, and other sectors. The population data selected were those for 2009 [13]. Furthermore, rainfall gradually cleans the atmosphere and the ground, and so total water extraction[2] (in millions of m^3) [14] was taken as a possible impact variable. Data on the area of woodlands and forests[3] [15] are also useful for measuring the degree of potential air purification. The relationship between degradation of forests and levels of air pollution is well established [16]. In our study, the total surface area [17] of each country was used to weight the above variables and thus standardize the compiled data.

In the analysis of the spatial dimension of the data, the regions are no longer considered as independent geographical bodies in order to incorporate the possibility of spatial interaction [18]. Spatial autocorrelation can be defined in a number of manners: Sokal and Oden [19], Tobler [20], and Upton and Fingleton [21]; following Cliff and Ord [22], it can be defined in this manner: "if the presence of some quantity in a county (sampling unit) makes its presence in neighbouring counties (sampling units) more or less likely, we say that the phenomenon exhibits spatial autocorrelation." Moran's Index [23-24] is commonly employed to measure spatial autocorrelation, calculated via the following equation:

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

…where n is the number of countries and $W = (w_{ij})$ is the matrix of spatial weights that determine the degree of contiguity between zones i and j. In this paper the w_{ij} contiguity measurement is considered as the inverse of the distance between capitals in each of the countries analyzed. The values of Moran's index oscillate between +1 (representing a strong positive spatial correlation) and -1 (representing a strong negative spatial correlation), while where no spatial correlation exists the index values will be close to zero.

Results and Discussion

As can be seen when the information is presented using a geographical information system [25], the population density is quite high in small countries such as Malta

[1] Croatia joined the EU on 1 July 2013. The data analyzed in this study had been extracted prior to 2013, so 27 countries were considered.

[2] Water removed from any freshwater source, either permanently or temporarily. Mine water and drainage water as well as water abstractions from precipitation are included, whereas water used for hydroelectricity generation (in situ use) is excluded.

[3] Forest area is land under natural or planted stands of trees of at least 5 m in situ, whether productive or not, and excludes tree stands in agricultural production systems (for example, in fruit plantations and agroforestry systems) and trees in urban parks and gardens.

(1,380 inhabitants per km^2), the Netherlands (486.2), and Belgium (348.3); the least densely populated countries are Finland (17.5 inhabitants per km^2) and Sweden (22.6). This situation strongly affects levels of air pollution; thus, Malta recorded the highest levels of all types of air pollution in the EU in 2009, which shows consistency with the environmental problems facing Malta, some of which have been addressed by different institutions, including the European Parliament [26]. Although no data are available for the forested area in Malta, the relationship between population density and forest area is apparent; for the EU as a whole, the value of Pearson's linear correlation coefficient [27] is -0.56 (p-value = 0.003) and these variables are significantly related to pollution levels.

The forest index (calculated as the ratio of forest area to total surface area) is high in Finland (0.726) and Sweden (0.686) and much lower in countries like Ireland (0.106; although here the total forest area has increased by 59% since 1990), and the Netherlands (0.107). This indicator has increased in all countries since 1990. The average forest index for the EU in 2010 was 0.34, which represents an increase of 13% since 1990, indicating that the overall situation in the EU has improved markedly in recent years and that the forestry policies being implemented are proving effective.

The statistics on the recorded emissions of CO_2 (in thousands of tons per km^2) in the EU in 2008 (except for Malta) show that the lowest values were recorded in Sweden (0.146), Latvia (0.147), and Finland (0.208), while the highest were found in the Netherlands (6.101) and Belgium (4.13). The EU average was 1.316. These data for 2008 are not encouraging, when compared with those for 1999; only eight countries reduced their levels of emissions (the best results being those of France, by 6.4%, and Slovakia, by 5.9%). In contrast, CO_2 emissions rose in Denmark by 42.2% and in Slovenia by 31%. Overall, the increases in CO_2 emissions exceeded the reductions.

The emissions of sulphur oxide also varied widely among the countries surveyed. The lowest values recorded in 2009 corresponded to Latvia (0.063 thousand tons per km^2) and Sweden (0.073), while the highest were found in Malta (24.817), followed at a considerable distance by Bulgaria (5.927) and Greece (3.237). The mean overall of emission level of sulphur oxide was 2.196 (1.326 excluding Malta). The evolution of these emissions over time is, nevertheless, very encouraging, since almost all countries have reduced their emissions since 2000. The reductions have been dramatic in Slovenia (87.48%), Hungary (83.69%), and Ireland (76.60%), but less than 20% in Turkey, Lithuania, and Greece. The exceptions are Romania, where they increased slightly (0.69%), and Luxembourg, where although the 2009 values in absolute terms were not very high, they had increased by 1,382% with respect to the year 2000. Overall, though, the policies adopted by the EU are having a positive effect in terms of reducing emissions of sulphur oxides, with an average reduction for the EU as a whole (excluding Luxembourg) of approximately 48%.

Nitrogen oxide emissions in 2009 also varied widely. The lowest values were recorded in Sweden (0.364 thousand tonnes per km^2), Latvia (0.440), and Finland (0.501), and the highest in Malta (27.083), the Netherlands (8.118), and Belgium and Luxembourg (above 6 in each case). The average level in the EU was 3.534 (2.629 excluding the anomalously high value of Malta). Compared to the year 2000, overall EU emissions fell by 25.77%, although results were very heterogeneous; levels fell in most countries in comparison with 2000, with the largest reductions in emissions being achieved by the United Kingdom (39.29%) and the Czech Republic, Belgium, Ireland, Denmark, Italy, and the Netherlands with reductions of over 30%. But levels rose in Luxembourg (with a dramatic increase of 2,083%), Lithuania (30.19%), and Greece (3.37%).

The average level of ammonia emissions in the EU in 2009 was 1.137 tons per km^2 – a reduction of 10.2% with respect to 2000. Again, Malta recorded the highest value (5.120), followed by the Netherlands (3.691) and Belgium (2.153). Sweden (0.117), Finland (0.120), and Estonia (0.229) reported the lowest rates. Most countries reduced their emissions compared to 2000 – especially in Bulgaria (52.98%) and the Netherlands (22.89%) – and emissions increased in only four countries, with the highest increase being recorded in Latvia (26.34%).

The mean level of emissions of 'Other compounds' in 2009 was 2.034 tons per km^2, which represents a decrease of 29.65% compared to 2000. By country, Malta again recorded the highest level at 7.470, followed by the Netherlands (4.529) and Italy (3.677). Finland (0.365) and Sweden (0.437) recorded the lowest emissions in 2009. Almost all countries managed to reduce their emissions in this respect, except for Bulgaria (increase of 42.40%), Romania (28.63%), and Poland (2.68%). The reductions were particularly pronounced in France (48.54%), Belgium (47.24%), and the United Kingdom (47.17%).

The differences in the values of freshwater extraction (in millions of m^3 per km^2, 2009 or latest available) are also very different between these countries. The Netherlands (0.312), Belgium (0.201), and Malta (0.110)

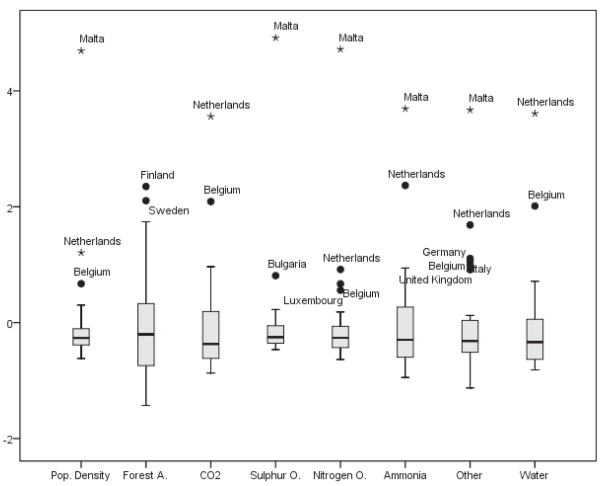

Fig. 1. Box-plot of standard values in the European Union.

Table 1. Moran's Index and p-values for European Union variables.

	I_ Moran	E(I)	V(I)	z(I)	*p-value
Population density	0.0159	-0.0385	0.0041	0.8479	0.3965
Forest area	0.1397	-0.0385	0.0042	2.7526	**0.0059**
CO_2	0.1339	-0.0385	0.0042	2.6730	**0.0075**
Sulphure O.	0.0140	-0.0385	0.0041	0.8196	0.4125
Nitrogen O.	0.0230	-0.0385	0.0041	0.9587	0.3377
Ammonia	0.0712	-0.0385	0.0042	1.6996	**0.0892**
Other compounds	0.0587	-0.0385	0.0042	1.5050	0.1323
Fresh water	0.0049	-0.0385	0.0041	0.6740	0.5003

**p-values less than .1 are highlighted.*

recorded the highest values, while Latvia (0.003), Sweden (0.006), and Ireland (0.010) reported the lowest.

The extreme values recorded for all the analyzed variables (Fig. 1) show that Malta and the Netherlands can be considered to show extreme outlier data in the EU, while in many cases Belgium is the 'standard' outlier. These data about Malta, Netherlands, and Belgium are in accordance with those described in the 2015 United Nations annual report [28], which states that concentrations of particulate matter and nitrogen oxides exceed the EU limit values. The evolution of Malta's greenhouse gas emissions is analyzed in [29].

Moran's I statistic for spatial autocorrelation was determined for each variable (Table 1), using the distances between the capitals of each country as weights. This statistic follows a normal asymptotic distribution under the hypothesis of independence of observations, which allows us to construct a test to measure the significance of the spatial autocorrelation [22].

Moran's I statistic determines whether the values of a variable are spatially clustered, dispersed, or are random. It usually takes values in the interval (-1, 1). If the values are grouped spatially, the indicator is positive and if they are dispersed it is negative. Values close to zero indicate randomness in the spatial distribution of observations [30]. In our case, the value is positive for all the variables analyzed, although the associated p-value leads us to reject the hypothesis of randomness in the spatial distribution only for the Forest Area, CO_2, and Ammonia variables, for which the Index I values are 1.1397, 0.1339, and 0.0712, respectively.

We make use of the existence of spatial clusters to apply cluster analysis of spatial patterns [31], by which missing values are replaced by the mean of the series. Hierarchical methods are used with the standardised variables (centroid clustering and Euclidean distance in the construction of the distance matrix), and the dendogram (Fig. 2) is obtained using R-project [32].

The first cluster is the largest, and consists of 14 countries: Austria, Bulgaria, Cyprus, Czech Republic, France, Greece, Hungary, Lithuania, Poland, Portugal, Romania, Slovakia, and Spain. The second is comprised of Estonia, Finland, Latvia, Slovenia, and Sweden. The third contains Denmark, Germany, Italy, Luxembourg, and the United Kingdom. Ireland joins the latter at some distance, followed by Belgium, the Netherlands, and especially Malta, at very considerable distances and thus forming isolated clusters: Ireland (4th cluster), Belgium (5th cluster), the Netherlands (6th cluster), and Malta (7th cluster). The centroids of these clusters (Table 2) reveal the differences between them: Cluster No. 1, the most numerous, presents average-level values for all variables; No. 2 presents low values for population density, high ones for forest cover, and low emission rates; while No. 3 has the highest population density, a low forest area, and relatively high levels of emissions. With respect to the countries forming isolated clusters, Belgium and the Netherlands have high values of population density, low levels of forest cover, and high

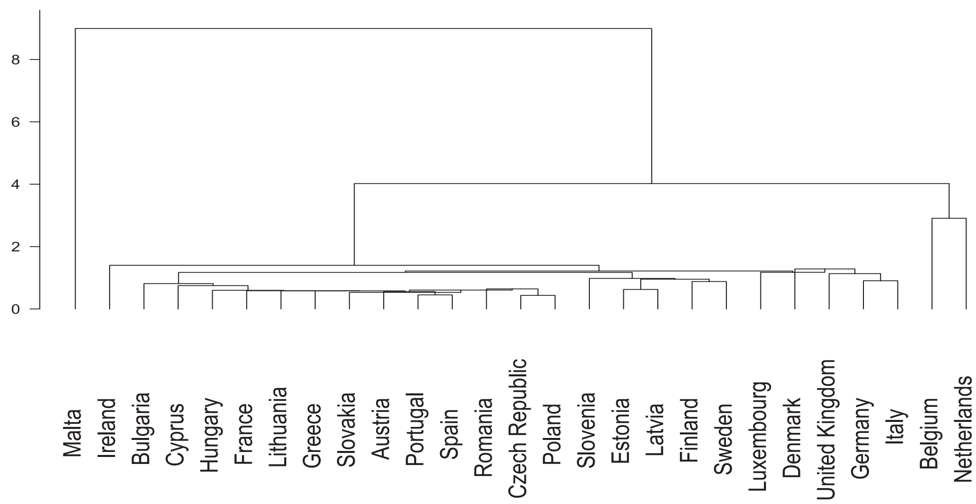

Fig. 2. Dendogram in the European Union.

Table 2. Cluster centroid for European Union variables.

Cluster	1	2	3	4	5	6	7
Population density	98.86	41.60	195.40	63.70	348.30	486.20	1,380.00
Forest area	0.32	0.61	0.23	0.11	0.22	0.11	0.34
CO_2	0.76	0.38	2.32	0.68	4.13	6.10	1.32
Sulphur O.	1.79	0.44	1.01	0.47	2.47	1.12	24.82
Nitrogen O.	2.07	0.85	4.19	1.29	6.88	8.12	27.08
Ammonia	0.70	0.32	1.48	1.54	2.15	3.69	5.12
Other compounds	1.55	0.83	2.89	0.75	3.50	4.53	7.47
Fresh water	0.05	0.03	0.05	0.01	0.20	0.31	0.11

emission values (these characteristics are magnified in the case of Malta, which represents an extreme case within the EU). Population density is a very important factor with respect to the other variables; a high population density directly impacts air pollution and indirectly on the forest area [33]. CO_2 levels are positively related to emissions of NO_2, ammonia, and other compounds, but are inversely related to emissions of sulphur oxides.

Conclusions

In summary, different patterns of behaviour can be found among EU countries for atmospheric indicators that impact the environment (Fig. 3). Among the clusters formed by a single country, the case of Malta stands out because of its bad records: the population density is high, and emissions of sulphur oxides, nitrogen oxides, ammonia, and other compounds are extreme. A similar

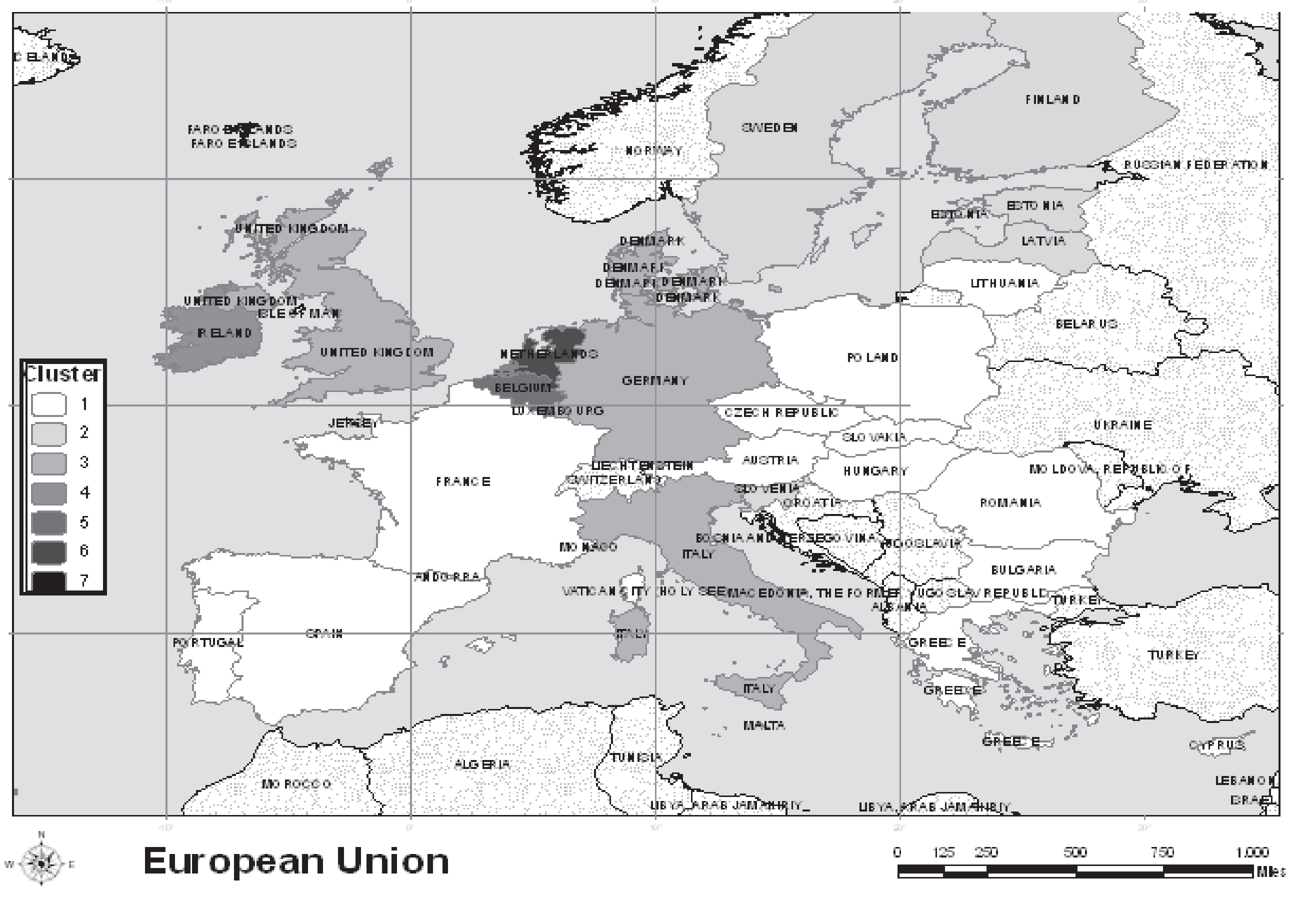

Fig. 3. Cluster for EU membership by each country.

pattern, although less extreme, is found in the Netherlands and in Belgium, where, in addition, levels of CO_2 and nitrogen oxide are high. However, these two countries present levels of freshwater extraction that are well above the EU average. As mentioned above, the outcomes for Malta, the Netherlands, and Belgium are in accordance with those described in the 2015 United Nations annual report, which states that concentrations of particulate matter and nitrogen oxides exceed the EU limit values.

The mean EU value could be associated with cluster No. 1, while No. 2 would be considered as more acceptable, being represented by a relatively low population density, considerable forest cover, and low levels of emissions to the atmosphere. Cluster No. 3 consists of countries with below-average results, with high population densities, low levels of forest area, and relatively high levels of emissions.

The analysis performed allows us to establish groups of countries according to their emissions. Regardless of these results, very high overall quantities are observed. Global harmonization of government emission control policies is therefore necessary.

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