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Heterogeneity in Air Pollution Levels and Their Techno-economic Determinants: A Cluster Analysis of the EU–27

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Abstract

The ongoing decline in environmental quality is one of the biggest global challenges facing humankind today. The purpose of this study is to investigate the differences and similarities among the EU–27 countries regarding air pollution emissions (greenhouse gases and acidifying gases) and their techno-economic determinants, which encompass economic, energy, innovation and institutional quality factors. The analysis covers nine indicators that reflect pollution emissions and fifteen variables that illustrate air pollution drivers. Cluster analysis of the data averaged for the period 2015–2020 was used to identify subgroups of countries. The results show that European Union (EU) countries substantially differ in terms of both air pollution levels and the determinants of the emissions. The analysis revealed a noticeable division between Eastern EU countries, which show similar patterns both in terms of pollution and determinants, and Western EU countries, which were characterised by greater diversity in terms of the analysed features. In light of the results, the assertion about backward and polluted new EU member states compared to more advanced and environmentally uncontaminated old EU countries appears to oversimplify the reality. The findings contribute to the ongoing discussion on environmental quality. Our results indicate the need and space for initiatives that address factors that influence air pollution in order to impede environmental degradation. However, due to the revealed heterogeneity among countries, the efforts should be tailored to the specific country's characteristics.

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JEL: O44, Q50, Q53, Q56

Introduction

The deterioration of environmental quality and its consequences are not only a focus of academics and researchers but also an important policy concern. Excessive greenhouse gas (GHG) emissions are recognised as the major reason for climate change, which may lead to more extreme weather events, biodiversity loss, forest fires, water scarcity, decreasing crop yields, and the disappearance of glaciers and rising sea levels. It may also affect people's health (European Parliament 2018; 2023). According to the European Environment Agency, air pollution is the largest environmental health risk in Europe (European Environment Agency 2023). Combating climate change is, therefore, the priority of the European Union's (EU) environmental policy. Article 191 (1) of the Treaty on the Functioning of the European Union provides the objectives of the policy, which include preserving, protecting, and improving the quality of the environment, protecting human health, the prudent and rational utilisation of natural resources, promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change (*Consolidated versions…* n.d.).

Regarding recent European Union activities to formulate policies aimed at environmental protection, The European Climate Law entered into force on 29 July 2021. This legal act wrote into law and made legally binding the goal proposed under the European Green Deal to reach EU climate neutrality by 2050, in line with the objectives of the Paris Agreement. This means that the EU as a whole should achieve net zero greenhouse gas emissions by 2050. The law also updated the EU's interim target of reducing net greenhouse gas emissions from 40% to at least 55% by 2030, compared to 1990 levels[1] (Regulation (EU) 2021/1119…).

The EU is a leader in tackling air pollution. The EU–27's[2] contribution to global greenhouse gas emissions decreased by 7.9 percentage points between 1990 and 2019 – from 15.2% to 7.3%. The corresponding drops reported for the United States and Russia were 6.9 and 4.9 percentage points, respectively. Nonetheless, in 2019, the EU–27 was still the world's fourth largest greenhouse gas emitter after China, the United States and India (Eurostat 2023, p. 75).

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[1] A review of the EU's environmental policies can be found in Cifuentes-Faura (2022) and Guterres (2022).

[2] EU member states as of February 2020.

In this context, the purpose of this article is to explore differences and similarities in air emissions and their techno-economic determinants across EU countries. Using cluster analysis, we aim to identify groups of countries (clusters) within the EU–27 that are similar. We intend to compare the identified groups and find patterns across clusters of EU countries. We consider this to be the main value added of the article. Air emissions used in the analysis encompass two groups of pollutants – greenhouse gases and acidifying gases. The variables that characterise the techno-economic determinants of air emissions cover economic, energy, innovation, and institutional quality indicators. Using only the most recent data available for 2020 could lead to biased results due to the outbreak of the COVID–19 pandemic, which drove a global slowdown and a reduction of emissions, especially in the first half of the year. Thus, to minimize the impact of cyclical fluctuations, the sample was extended, and all variables were calculated as the 2015–2020 average.

We hope that the research findings will contribute to the discussion about environmental quality and draw attention to the choice of measures available, which should take into account the diversity of each country.

The structure of the article is as follows. The next Section illustrates air pollution in the EU–27 and introduces air emission determinants based on a literature review. Section 3 describes the methodology and data, while Section 4 presents the results of the comparative analysis. The last Section concludes.

Air pollution and its determinants

The deterioration of environmental quality is a global concern due to its negative consequences. Greenhouse gases are recognised as the major reason for climate change (Aghel, Sahraie, and Heidaryan 2020). Meanwhile, acidification arising from acidifying gases may be detrimental to soils, plants and aquatic animals (Singh and Agrawal 2008, p. 15; Aung, Fischer, and Azmi 2020, p. 1760) and may affect human health (Singh and Agrawal 2008, p. 15). Acid rain is considered one of the most serious environmental issues (Singh and Agrawal 2008, p. 15). Although the EU implemented measures to reduce air pollution, the average 2019 EU–27 emissions of greenhouse gases per capita in CO_2 equivalent was 7.6 tonnes, about 25% higher than the world average (Eurostat 2023, p. 76). For reference, the biggest emitters, the United States and China, reached 18.3 and 9.0 tonnes, respectively (Eurostat 2023, p. 76).

Figure 1 presents greenhouse gas (GHG) emissions in CO_2 equivalent in tonnes per capita and total emissions in millions of tonnes for the EU–27 computed as the 2015–2020 average. Greenhouse gases comprise carbon dioxide (CO_2), methane (CH_4), nitrous oxide

(N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) in CO_2 equivalent.

Figure 1 shows that the top four EU–27 emitters in per capita terms were Luxembourg (14.2 tonnes per capita), Denmark (13.7), Estonia (12.6) and Ireland (12.5). By contrast, Malta (4.2), Sweden (4.5), Croatia (4.5) and France (4.9) were in the bottom four. In terms of total emissions, Germany, Poland, France, and Italy accounted for the largest share of air pollution, with emissions of 709.6, 353.9, 329.8 and 326.1 million tonnes, respectively. The smallest contributors were Malta (2.0 million tonnes), Cyprus (6.9), and Luxembourg (8.5).

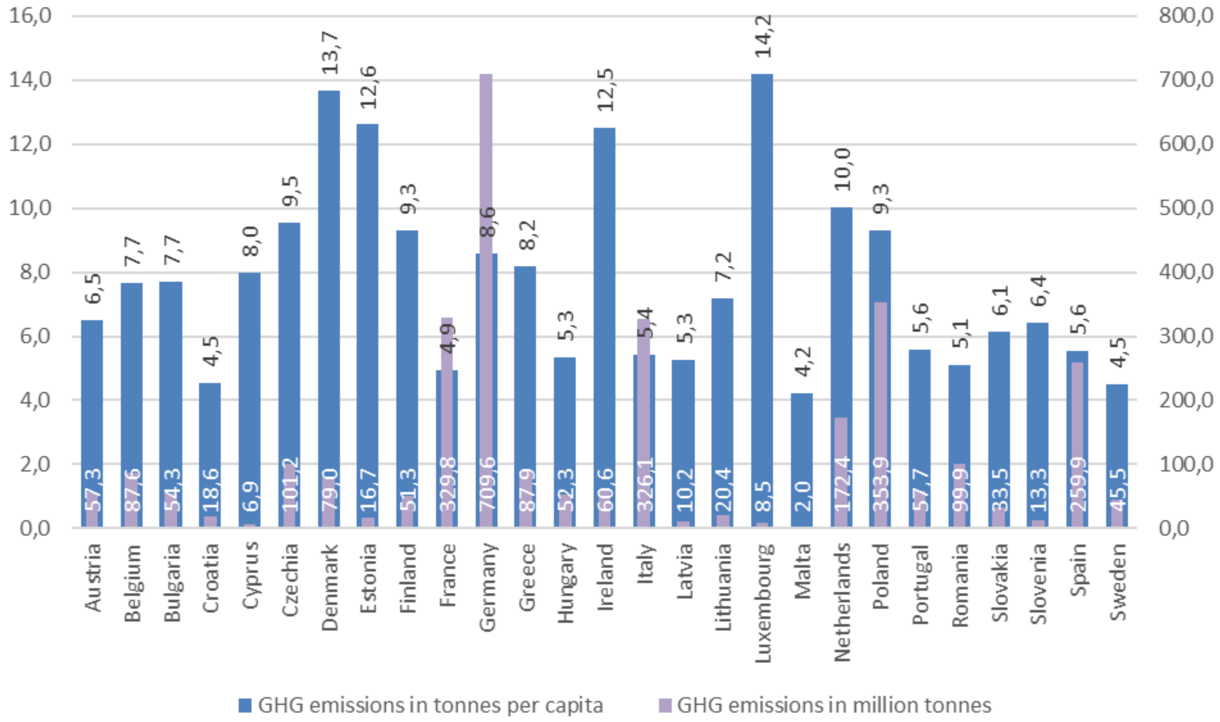

Figure 1. Greenhouse gas emissions in CO_2 equivalent in tonnes per capita (left axis) and millions of tonnes (right axis) for the EU–27 countries – 2015–2020 average.

Source: own elaboration based on Eurostat database.

Figure 2 shows acidifying gas (ACG) emissions in SO_2 equivalent in kilograms per capita and total emissions in thousands of tonnes[3] for the EU–27 calculated as the 2015–2020 average. Acidifying gases include sulphur oxides (SO_x), nitrogen oxides (NO_x) and ammonia (NH_3) in SO_2 equivalent.

Figure 2 shows that Malta, Slovakia, Croatia, and Belgium emitted the least amount of acidifying gases in per capita terms, i.e., 15.3, 20.5, 21.7 and 21.8 kilograms per inhabitant. Denmark was the biggest emitter (240.1 kilograms per capita), followed by Greece (69.6) and Ireland (62.7). Concerning total emissions, Germany and France were

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[3] Data labels for total emissions are omitted to improve the figure readability.

the main sources of acidifying gases, with emissions of 2,517,518 and 1,733,543 tonnes, respectively. Next were Spain (1,583,241), Italy (1,478,820), Poland (1,434,035), and Denmark (1,384,473). By contrast, Malta (7247), Luxembourg (32,015) and Cyprus (37,044) emitted the least.

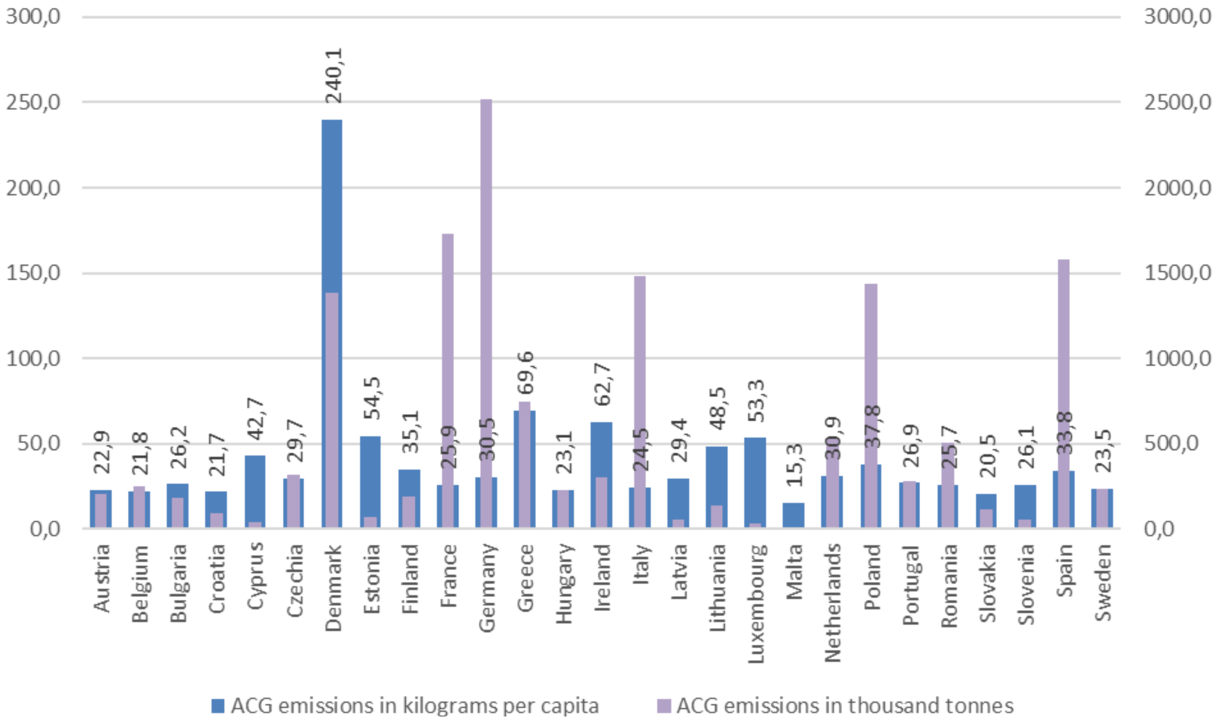

Figure 2. Acidifying gas emissions in SO_2 equivalent in kilograms per capita (left axis) and thousands of tonnes (right axis) for the EU–27 – 2015–2020 average

Source: own elaboration based on Eurostat database.

Our empirical analysis presented in the next section is dedicated to clustering the EU–27 countries according to their air pollution and its determinants. The set of potential determinants of air emissions was selected based on a literature review. A vast amount of literature examines the determinants of air pollution, especially within the environmental Kuznets curve (EKC) framework. The standard EKC proposes an inverted U-shaped relationship between per capita income and environmental quality, stating that pollution increases at the beginning of the development process and then starts to decrease after reaching a certain income threshold. Under the EKC hypothesis, two factors that shape environmental quality are commonly considered – per capita income and a measure of energy consumption. As different measures show different aspects of energy consumption, empirical studies use several indicators (see, e.g., Wu 2017; Arminen and Menegaki 2019; Du, Li, and Yan 2019; Işik, Ongan, and Özdemir 2019; Ehigiamusoe, Lean, and Smyth 2020; Ongan, Isik, and Ozdemir 2020; Wawrzyniak and Doryń 2020; Bekun et al. 2021; Mehmood et al. 2021; Karim et al. 2022; Khan, Weili, and Khan 2022; Wang, Yang, and Li 2023).

On this basis, we chose four variables for our analysis – GDP per capita, which serves as an economic indicator, and three energy indicators, i.e., final energy consumption per capita, share of fossil fuels in gross available energy, and share of energy from renewable sources.

A growing number of studies have investigated the technology-related determinants of air emissions (e.g., Weina et al. 2016; Cheng et al. 2019; Du, Li, and Yan 2019; Wang, Zeng, and Liu 2019; Bai et al. 2020; Cheng et al. 2021; Chien et al. 2021; Shan et al. 2021; Jinqiao et al. 2022; Lingyan et al. 2022; Zheng, Lv, and Wang 2022). Technology innovations, especially green ones, may substantially help mitigate air pollution and facilitate progress towards environmental sustainability (Chien et al. 2021; Shan et al. 2021; Lingyan et al. 2022, pp. 753–754). As innovation has many dimensions, our analysis comprises six indicators: patent stock in all technologies per capita, patent stock in environment-related technologies per capita, patent stock in environment-related technologies associated with air pollution abatement per capita, R&D expenditure stock in % of GDP, researchers in R&D per million people, and gross enrolment ratio for tertiary education in %.

In addition to the factors above, many studies focused on aspects related to the impact of institutional background on environmental pollution (Wu 2017; Gholipour and Farzanegan 2018; Arminen and Menegaki 2019; Wawrzyniak and Doryń 2020; Bekun et al. 2021; Mehmood et al. 2021; Karim et al. 2022; Khan, Weili and Khan 2022). Thus, we extended the set of variables to include institutional quality indicators, namely government effectiveness, control of corruption, and rule of law.

Several other factors that affect air emissions were also discussed in the literature. One of them is the industrial structure (Zhang et al. 2014; Gholipour and Farzanegan 2018; Liu and Bae 2018; Du, Li, and Yan 2019; Bai et al. 2020; Yildirim, Alpaslan, and Eker 2021; Jinqiao et al. 2022; Wang, Yang, and Li 2023). It was argued and verified that the tertiary sector has a carbon emission-reducing influence (Zhang et al. 2014) while the secondary sector has an increasing carbon emission effect (Liu and Bae 2018; Du, Li, and Yan 2019). So, we utilised two variables to represent the industrial structure, i.e., industry (including construction) value added in % of GDP and services value added in % of GDP.

Methodology and data

The empirical part of the paper is dedicated to identifying groups of countries (clusters) within the EU–27[4] that are similar in terms of two criteria: (i) emissions of greenhouse and acidifying gases and (ii) determinants of air pollution. Thus, the cluster analysis

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[4] EU member states as of February 2020.

for the 2015–2020 average was applied twice, separately for each criterion described by a distinctive group of variables.

The first input data set includes nine variables that report greenhouse and acidifying gas emissions by pollutants, i.e.:

1. Greenhouse gases:

X_1 – carbon dioxide (CO_2) emissions in kilograms per capita,

X_2 – methane (CH_4) emissions (CO_2 equivalent) in kilograms per capita,

X_3 – nitrous oxide (N_2O) emissions (CO_2 equivalent) in kilograms per capita,

X_4 – hydrofluorocarbon (HFC) emissions (CO_2 equivalent) in kilograms per capita,

X_5 – perfluorocarbon (PFC) emissions (CO_2 equivalent) in kilograms per capita,

X_6 – nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) emissions (CO_2 equivalent) in kilograms per capita.

2. Acidifying gases:

X_7 – sulphur oxide (SO_x) emissions (SO_2 equivalent) in kilograms per capita,

X_8 – nitrogen oxide (NO_x) emissions (SO_2 equivalent) in kilograms per capita,

X_9 – ammonia (NH_3) emissions (SO_2 equivalent) in kilograms per capita.

All emissions data come from Eurostat.

The second input data set comprises fifteen variables that represent the techno-economic determinants of air pollution divided into four groups, covering:

1. Economic indicators:

Y_1 – GDP per capita in constant 2015 US$,

Y_2 – industry (including construction) value added in % of GDP,

Y_3 – services value added in % of GDP.

2. Energy indicators:

Y_4 – final energy consumption (energy use) in thousand tonnes of oil equivalent per capita,

Y_5 – share of fossil fuels in gross available energy (in %),

Y_6 – share of energy from renewable sources (in %).

3. Innovation indicators:

Y_7 – patents stock in all technologies per capita,

Y_8 – patents stock in environment-related technologies per capita,

Y_9 – patents stock in environment-related technologies associated with air pollution abatement per capita,

Y_{10} – R&D expenditure stock in % of GDP,

Y_{11} – researchers in R&D per million people,

Y_{12} – gross enrolment ratio for tertiary education (in %).

4. Institutional quality indicators:

Y_{13} – government effectiveness,

Y_{14} – control of corruption,

Y_{15} – rule of law.

The economic indicators data are obtained from the World Development Indicators (WDI) database of the World Bank. The energy indicators come from the Eurostat[5] database, while the institutional quality indicators are from the World Governance Indicators (WGI) database (Kaufmann and Kraay 2023), which follows the methodology of Kaufmann, Kraay, and Mastruzzi (2010). The innovation indicators come from diverse sources. The researchers in R&D and gross enrolment ratio for tertiary education[6] variables are sourced from the WDI database. The next four variables, which measure patent stocks and R&D expenditure stocks, are calculated based on data from the OECD and WDI databases, respectively.

We followed the perpetual inventory method to estimate the stocks from data on flows of patents and R&D expenditures. The stock measures were calculated using the following formula (cf. Piva and Vivarelli 2018):

$$innov\_stock = \begin{cases} \dfrac{innov\_flow}{g+\delta} \, for\, t = 0 \\ (1-\delta) innov\_stock + innov\_flow \, for\, t > 0 \end{cases} \tag{1}$$

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[5] Data are converted into per capita using population figures from the World Development Indicators (WDI) database.

[6] Due to a break in data, the value of the variable for Greece in 2015 is calculated as the average of 2014 and 2016, for the Netherlands in 2019 – the average of 2018 and 2020, and for Estonia, the value of the variable in 2020 is set at the 2019 level.

where *innov_stock* represents a stock measure of the corresponding flow (*innov_flow*) indicator, g is the 2005–2020 compound growth rate[7] of the *innov_flow*, and δ denotes the depreciation rate. For the depreciation rate, we have adopted the value of 20% as a compromise between the estimates of 0% and 40% provided by Hall (2007) for R&D.

Considering that stock values are highly dependent on their initial estimates (for $t = 0$), we have computed the stocks for 2005–2020, ensuring that the initial values depreciate over time. This allowed us to enhance the reliability of the stock estimates for the period 2015–2020. The stock values were converted into per capita terms using the population figures from the WDI database.

Research results

We employed clustering to analyse and compare the air pollution in EU countries and the factors that determine pollution emissions. Clustering involves grouping similar objects (countries) into homogeneous groups based on the multivariate distance between the objects. In this study, the similarity between the countries was calculated using the Euclidean distance, which is one of the most commonly used metrics. In this metric, the proximity between two observations (points on a plane) is determined in geometric terms by the length of a line segment connecting them, which can be expressed in multivariate space as:

$$dist_{Euc} = \sqrt{\sum_{i=1}^{n}\left(x_i - y_i\right)^2}, \tag{2}$$

where $dist_{Euc}$ is the Euclidean distance between objects x and y in the space of n parameters, while x_i and y_i is the i-th element (dimension) of objects x and y, respectively. As we had no preliminary knowledge of the number of clusters in our data, we applied the hierarchical cluster analysis (Hastie, Tibshirani, and Friedman 2009, p. 520; Kula and Ünlü 2019, p. 239), which aims to build a hierarchy of clusters (visualised as a tree diagram or dendrogram). We used the Ward linkage method in agglomerative hierarchical clustering, one of the most commonly used techniques in air pollution studies (Govender and Sivakumar 2020). The algorithm starts with singletons (every object that forms its own cluster in the leaves of the dendrogram) and then, at each iteration, joins two clusters based on the smallest increase in total within-cluster variance after merging. The procedure ends with a hierarchy of clusters (when all observations belong to a single cluster at the root of the tree diagram) (Nielsen 2016, pp. 221–222).

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[7] Negative growth rates were replaced with zeros.

We omitted highly correlated variables (with a Pearson correlation coefficient greater than 0.8) and standardised input variables by subtracting their mean and dividing them by their standard deviation so that the data have a mean of 0 and a variance of 1. The standardisation equalised the weighting of each input variable (dimension) and ensured that the clustering was not based on the variability of dimensions (Jajuga and Walesiak 2000, p. 106). The final list of variables includes: X_1, X_2, X_3, X_4, X_5, X_6, X_7 and Y_1, Y_3, Y_5, Y_6, Y_9, Y_{10}, Y_{12}, Y_{14}.

Figure 3 shows the results of the cluster analysis based on the countries' air pollutant emissions (greenhouse gases and acidifying gases), and Figure A1 in the Appendix shows the scaled values of the variables examined in the determined clusters.

As determining the number of clusters is largely arbitrary (OECD 2008, p. 76), we decided to distinguish five clusters of countries. Table 1 presents the extracted groupings. The cluster analysis revealed the outlier position of Denmark and Ireland (clusters 1 and 2). Denmark has the EU's highest sulphur oxide emissions in kilograms per capita terms, the second-highest level of methane, and the third-highest level of nitrous oxide emissions. However, it had one of the lowest hydrofluorocarbon emissions. Ireland has the highest emissions of both methane and nitrous oxides and relatively high perfluorocarbon emissions, but the lowest sulphur oxide emissions. Both countries are also characterised by relatively high carbon dioxide emissions.

Cluster 3 comprises countries that have high hydrofluorocarbon and relatively high perfluorocarbon emissions while maintaining mostly low levels of the other analysed pollutants. The countries in cluster 4 exhibit high levels of nitrogen trifluoride and sulphur hexafluoride and relatively low levels of sulphur oxide emissions. Cluster 5 covers nearly all new EU member states whose emissions (mostly) follow the pattern of mean emissions in the EU–27.

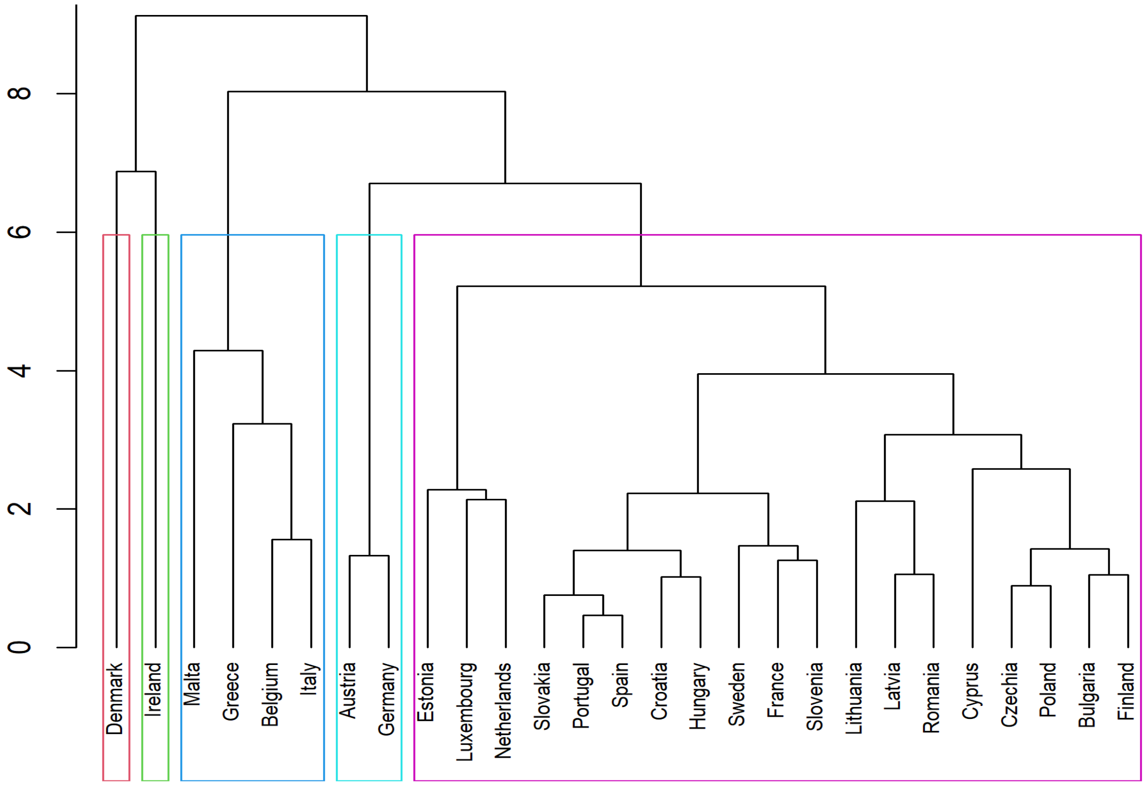

Figure 3. Dendrogram derived for air pollution of the EU–27 countries

Source: own elaboration.

Table 1. Cluster composition – air pollution

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Denmark	Ireland	Belgium, Greece, Italy, Malta	Austria, Germany	Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, France, Hungary, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden

Source: own elaboration.

Figure 4 presents the results of cluster analysis based on the factors that determine pollutant emissions. In this case, we also extracted five groupings of countries. Table 2 presents the structure of the clusters. Figure A2 in the Appendix illustrates the levels of the variables analysed in each cluster.

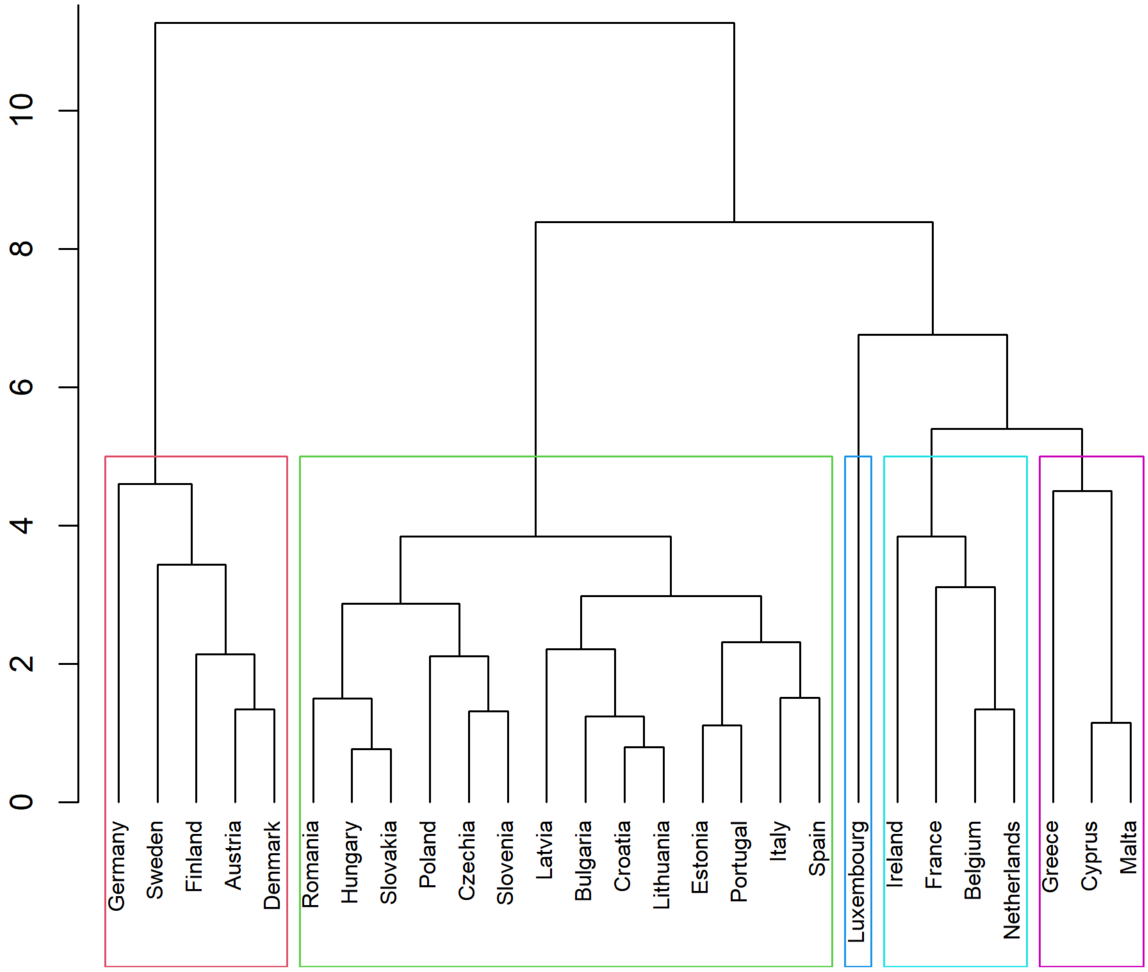

Figure 4. Dendrogram derived for air pollution determinants of the EU–27 countries

Source: own elaboration.

Table 2. Cluster composition – air pollution determinants

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Austria, Denmark, Finland, Germany, Sweden	Bulgaria, Croatia, Czechia, Estonia, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain	Luxembourg	Belgium, France, Ireland, the Netherlands	Cyprus, Greece, Malta

Source: own elaboration.

Cluster 1 comprises countries with the highest stock of R&D expenditures, a high stock of patents in air pollution abatement technologies, a mostly high share of energy from renewable sources, an above-EU average GDP per capita, and strong institutions (measured by the control of corruption index). Cluster 2 is dominated by the new EU member states, with low levels of GDP per capita and low innovation performance regarding patent stocks in technologies associated with air pollution abatement and stock of (total) R&D expenditures. Moreover, this group's share of services in GDP is mostly below the EU average, with low levels of institutional quality. Cluster 3 is formed solely by Luxembourg. It is considered an outlier as it has the highest GDP per capita, the highest share of services in GDP, the lowest renewable energy consumption, the lowest tertiary school enrolment, and high institutional quality. Cluster 4 contains rich countries with a relatively high stock of R&D spending and a stock of patents in air pollution abatement technologies close to the EU average. They have a low share of energy from renewable sources and high institutional quality. Cluster 5 is characterised by a higher than EU average share of the service sector in GDP, a high share of fossil fuel energy consumption combined with a low share of energy from renewable sources, and low innovation performance measured by patent stocks in technologies associated with air pollution abatement and stock of (total) R&D expenditures.

Conclusion

The article presented the results of an analysis of the differences (and similarities) of EU countries in terms of air pollution emissions and their techno-economic determinants. We conducted a cluster analysis on preselected sets of indicators using averaged data for 2015–2020. Groups (clusters) of countries that were similar in terms of the considered characteristics were identified, and thus, we achieved our research goal. Our findings confirm that individual groups of countries exhibit distinctive patterns of air pollution, as well as factors that determine the emissions. In both groupings, the Eastern EU countries formed a separate cluster, revealing homogeneity both in terms of pollution and its determinants. Western EU countries showed greater diversity in terms of the variables analysed: some showed levels of air pollution intensities similar to those of Eastern EU countries (i.e., Finland, France, Luxembourg, Spain, and Sweden) and factors that determine pollution similar to Eastern EU countries (i.e., Italy, Portugal, and Spain), while the others formed the remaining clusters. As far as Cyprus and Malta are concerned, in the case of clustering based on the determinants of pollution, they formed a separate cluster together with Greece. When analysing the pollution levels, however, only Malta showed a different pollution pattern, while Cyprus was included in the Eastern EU cluster. Therefore, in light of our results, the conclusion about backward and 'dirty' new member states and advanced and 'clean' old EU countries would be a far-reaching simplification of reality.

The multivariate analysis leads to the conclusion about the heterogeneity of the EU regarding both air pollutant emissions and the factors that potentially affect pollution levels. The analysis indicates that there are still significant differences between EU members and that much still needs to be done to improve air quality. The results of this study may contribute to the debate on environmental protection. The findings indicate the need and space for initiatives in the area of factors that influence air pollution in order to impede environmental degradation, though there may be no single recipe for all EU countries. The revealed heterogeneity among countries suggests that the actions should address a country's specific settings.

According to the World Health Organization (2021, pp. 13–15), bad air quality has strong adverse health effects, including increased premature mortality. Therefore, reducing air pollution should be a priority for all countries that exceed acceptable emissions levels. Current WHO air quality guidelines are more stringent than EU standards, and only long-term EU policies aim to reduce environmental pollution to health-safe levels. However, given the current progress in meeting the EU air pollution targets by individual member states, it will be challenging to meet further pollution reductions.

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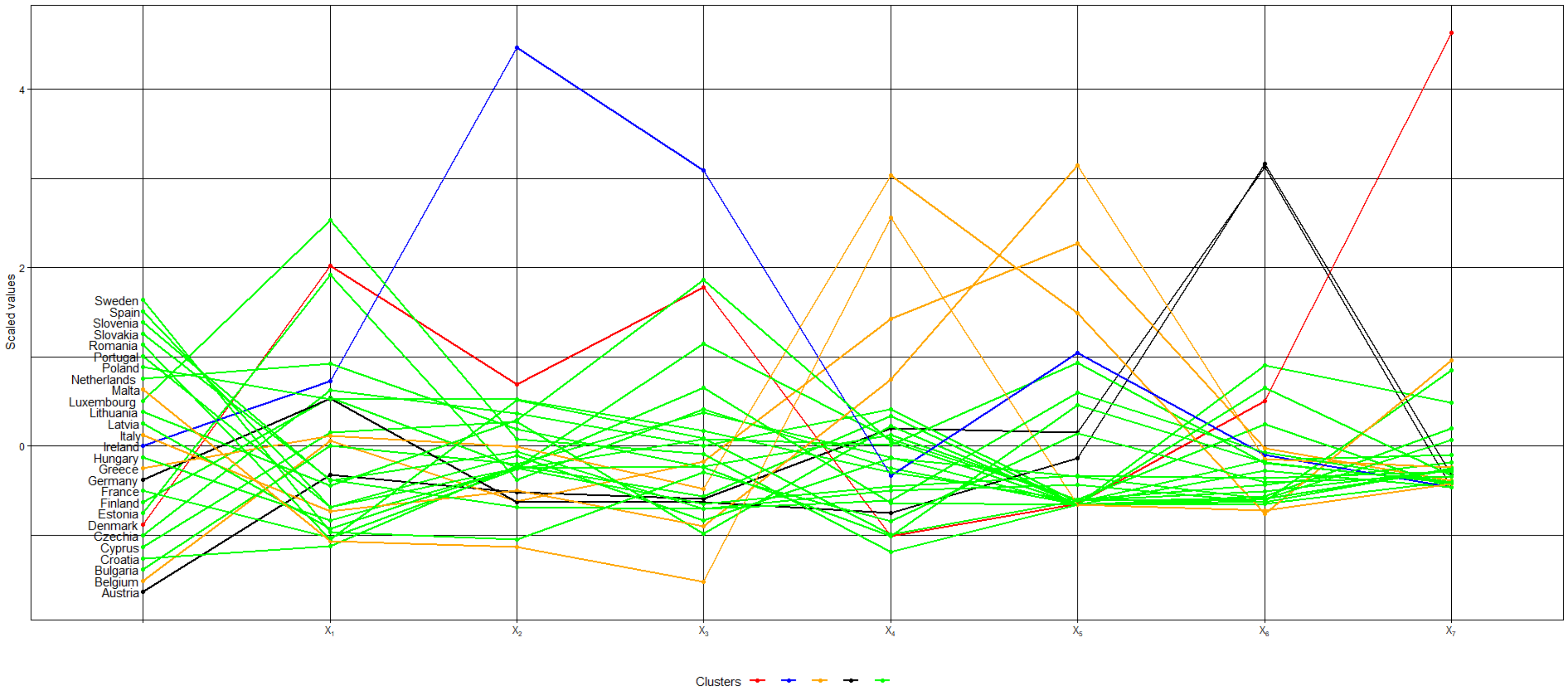
Zróżnicowanie poziomu zanieczyszczenia powietrza i jego uwarunkowań techniczno-ekonomicznych: analiza skupień dla krajów UE–27

Ciągłe pogarszanie się jakości środowiska naturalnego jest jednym z najważniejszych globalnych wyzwań, przed którymi stoi obecnie ludzkość. Celem niniejszego badania była analiza różnic i podobieństw między krajami UE–27 w zakresie emisji zanieczyszczeń powietrza (gazów cieplarnianych i gazów zakwaszających) oraz ich uwarunkowań techniczno-ekonomicznych, obejmujących czynniki ekonomiczne, energetyczne, instytucjonalne oraz poziom innowacyjności. Analizę przeprowadzono na podstawie dziewięciu wskaźników ilustrujących emisje zanieczyszczeń oraz piętnastu zmiennych reprezentujących determinanty zanieczyszczenia powietrza, wykorzystując ich średnie wartości z lat 2015–2020. Do zidentyfikowania podgrup krajów o podobnych wzorcach zastosowano analizę skupień. Otrzymane wyniki wskazują na znaczące zróżnicowanie krajów UE zarówno pod względem poziomów zanieczyszczenia powietrza, jak i determinant emisji. Przeprowadzona analiza ujawniła istotne różnice pomiędzy wschodnimi krajami UE, wykazującymi wspólne wzorce zanieczyszczeń powietrza i determinant emisji, oraz zachodnimi krajami UE, które cechowały się większym zróżnicowaniem pod względem analizowanych cech. W świetle uzyskanych wyników twierdzenie o zacofanych i zanieczyszczonych nowych państwach członkowskich UE w porównaniu z bardziej zaawansowanymi i nieskażonymi środowiskowo starymi krajami UE wydaje się nadmiernie upraszczać rzeczywistość. Nasze wyniki stanowią wkład w toczącą się dyskusję na temat jakości środowiska. Wskazują na potrzebę i przestrzeń do podjęcia działań w obszarze czynników wpływających na zanieczyszczenie powietrza w celu zahamowania degradacji środowiska naturalnego. Niemniej jednak, ze względu na ujawnioną heterogeniczność między krajami, wysiłki powinny być dostosowane do ich specyfiki.

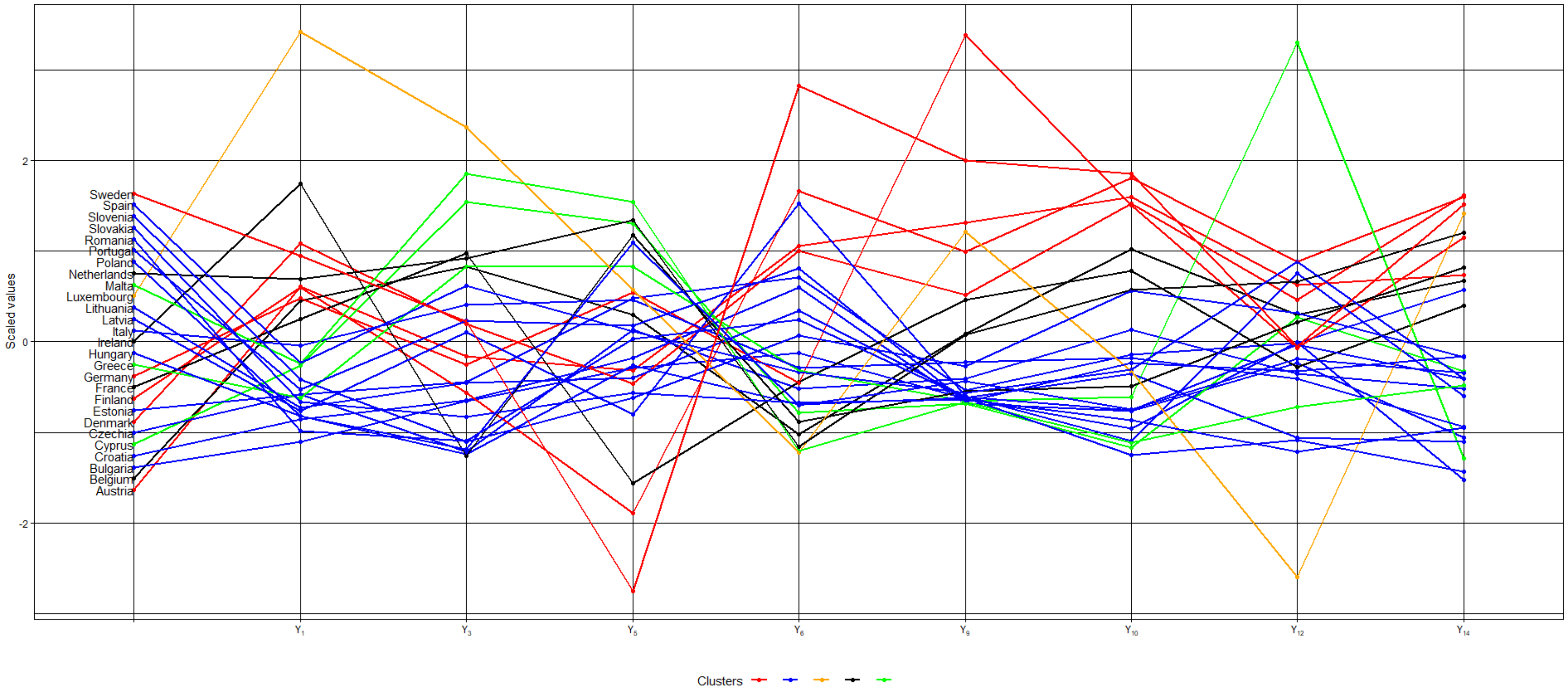
Słowa kluczowe: zanieczyszczenie powietrza, emisja gazów cieplarnianych, emisja gazów zakwaszających, analiza skupień, kraje Unii Europejskiej

Appendix A1. **Country air pollutant emissions of the EU–27 by cluster**



Source: own elaboration.

Appendix A2. Country determinants of air pollution among the EU–27 by cluster



Source: own elaboration.