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AIR QUALITY IN THE CONTEXT OF ITS MONITORING IN CENTRAL AND EASTERN EUROPE IN 2010-2020

Abstract

The purpose of this article is to discuss the issue of air quality monitoring by means of Sustainable Development Indicators (SDIs), and to present the changes in Central and Eastern European (CEE) countries that have taken place in this respect. Statistical analysis, Ward's method, and a review of research on air quality and its monitoring in terms of sustainable development are employed. The analysis was performed in order to identify groups of EU countries that are similar in terms of air quality and to identify the changes that have taken place in these countries, accounting for it. It becomes important to monitor air quality, including greenhouse gas emissions in countries that are working towards sustainable development goals, and thus to analyse the changes taking place there. The analysis of air quality in the CEE countries for the period 2010–2020 has shown that these countries are gradually reducing emissions of air pollutants and increasingly using renewable energy sources. On the other hand, a study of the situation in the CEE countries when compared to the rest of the EU showed that in 2020, new EU Member States (eight countries) and Greece were among the countries where the problem of greenhouse gas emissions should be considered significant. The demands of climate and environmental protection are assessed through the prism of both economic and social considerations. In this context, the monitoring of air quality is at the centre of the EU's and Member States' attention through Sustainable Development Indicators, measuring progress towards sustainable development goals. The proposed classification should facilitate the mapping of air quality variability in the EU, including the CEE countries, and its monitoring.

Keywords: *air quality, monitoring indicators, monitoring of air quality, Sustainable Development Indicators, Central and Eastern European countries*

Introduction to air quality issues

Air pollution is becoming an increasingly serious problem for populations around the world, especially in large cities. Data from the European Environment Agency shows that in 2021, 97% of urban residents in the EU were exposed to elevated levels of fine particulate matter exceeding WHO standards (European Environment Agency, 2024a). Concentrations of other pollutants also often exceed recommended guidelines. Population growth and the development of urban agglomerations both increase emissions and reduce the ability to remove pollutants efficiently, causing them to accumulate. Dense urban development impedes airflow by reducing wind speeds in the near-surface layer, resulting in the accumulation of pollutants. Buildings not only inhibit the removal of pollutants, but are also an additional source of emissions, mainly from heating systems. The increasing number of vehicles also contributes to the deterioration of air quality. The lack of traffic flow in cities, often due to incorrectly configured traffic lights and insufficient capacity of the traffic system, exacerbates the problem. In addition, vehicle traffic influences the re-introduction into the air of pollutants previously deposited on the ground (Godłowska, 2019, p. 9).

Improving air quality requires the use of alternative energy sources that reduce emissions of harmful substances from the combustion of traditional energy carriers. For example, the use of solar energy reduces emissions of CO2, SO2, CO, nitrogen compounds, and dust (Proszak-Miąsik, Nowak, Rabczak, 2013). Air quality is also affected by meteorological conditions. Wind direction and speed determine the influx and dispersion of pollutants. In addition to anemometric conditions, air quality is mainly shaped by temperature and relative humidity, an increase of which in turn contributes to a decrease in emissions (Czarnecka, Nidzgorska-Lencewicz, 2008).

Nowadays, there is growing evidence that air pollution has a major impact on life expectancy and quality of life. A higher number of hospitalisations and deaths than usual is observed during smog incidents (Dockery, Pope, Xu, Spengler, Ware, Fay, Ferris Jr, Speizer, 1993; Bell, Davis, 2001). Children are particularly vulnerable to the effects of poor air quality. Another high-risk group is the elderly, as long-term exposure to high concentrations of air pollutants increases the risk of death from lung cancer, as well as respiratory and cardiovascular diseases (Dockery, Pope, Xu, Spengler, Ware, Fay, Ferris Jr, Speizer, 1993; Neupane, Jerrett, Burnett, Marrie, Arain, Loeb, 2010). There is a statistically significant relationship between smog incidents and the occurrence of acute respiratory symptoms resulting in increased hospital admissions for asthma. The changing ranges of e.g. insect and arachnid species – which may in effect increase the risk of malaria, among other diseases – are also among problematic effects of climate change, and another effect of a warming climate is the increasing incidence of Lyme disease and the increased risk of heart attack and significantly less successful outcomes of its treatment (PolitykaZdrowotna.com, 2018). Air quality is therefore an important parameter, translating into human well-being and health. Therefore, its continuous monitoring, control, and determining the content of pollutants present in it at different concentration levels becomes crucial (Zabiegała, Partyka, Namieśnik, 2003). Ensuring good air quality has become a focus of attention in the EU and its Member States by taking measures for its systematic monitoring, also using SDIs.

The aim of the paper is to discuss the monitoring of the air quality in the European Union and to present the changes in the countries of Central and Eastern Europe in terms of air quality. The air quality in Central and Eastern European countries is also discussed against the other EU countries in 2010–2020 and they are classified with the use of the selected set of indicators. The proposed classification should facilitate the mapping of air quality diversification in the EU and its monitoring.

Research methods

The following research methods have been applied in the paper: statistical analysis, Ward's method, and review of research on air quality and its monitoring in terms of sustainable development.

Ward's method belongs to the agglomerative methods. Agglomeration methods involve a process of grouping from individual objects to a single group that brings them all together. Based on measures of distance or similarity, objects are grouped (agglomerated) according to how much they differ from each other or how similar they are. Agglomerative grouping leads to the creation of a connection tree (dendrogram), representing the salient features of the merging carried out. Groups of objects that are similar to each other form separate branches on this tree (Balicki, 2009, p. 259; Panek, 2009, pp. 91–93).

Ward's method uses a variance analysis approach to determine the distance between clusters. The method seeks to minimise the sum of the squares of deviations of any two clusters that can be formed. Thus, two groups of objects are combined into a single group to minimise the sum of squares of the deviations of all objects belonging to these two groups from the centre of gravity of the new group. This new group is the combination of the two groups.

At each stage of combining groups of objects, those groups are combined into a single group, which forms the group of objects with the least variation, given the variables that describe them (StatSoft, 2024; Panek, 2009, p. 91, pp. 95–96). The measure of cluster distance was the Euclidean metric. Calculations were performed using the STATISTICA software.

Review of research on air quality and its monitoring in terms of sustainable development

In recent years, scientific research on air quality and its monitoring in terms of sustainable development has become an important area of interdisciplinary research. Both natural and social scientists have contributed to this field.

One of the leading researchers is Mark Z. Jacobson of Stanford University, who analyses the effects of air pollution on human health and climate. His research often uses three-dimensional (3-D) computer models of the atmosphere and solvers to simulate air pollution and renewable energy systems, and to predict greenhouse gas (GHG) emissions and their consequences for global warming. His work has had a significant impact on climate and environmental policy making (Jacobson, 2023; Jacobson, 2021). Globally, Maria Neira of the World Health Organisation (WHO) has also made important contributions to air quality research. Her work focuses on the health aspects of air pollution and provides the foundation for a number of global strategies and sustainability indicators on public health (PolitykaZdrowotna.com, 2018). In the European context, on the other hand, it is worth noting the European Environment Agency's research on greenhouse gas emissions in Europe and their impact on air quality and climate change, especially the development of sustainability indicators that help monitor progress in reducing emissions and improving air quality (European Environment Agency, 2024b). In contrast, the work of Veerabhadran Ramanathan of the University of California, San Diego, looks at the impact of different types of pollutants on global warming, including aerosols and black carbon. He is also involved in initiatives to implement sustainability indicators into pollution monitoring and reduction practice

(Ramanathan, Wallack, 2009). Also noteworthy is the work of Deliang Chen from the University of Gothenburg, whose research focuses on climate change and its impact on air quality. He is working on developing global climate models, which are key to understanding the dynamics of greenhouse gas emissions and implementing the appropriate sustainability indicators (Shen, Li, Yuan, Yu, Lei, Chen, 2024; Yun, Ciais, Zhu, Chen, Zohner, Tang, Qu, Zhou, Schimel, Zhu, Shao, Christensen, Wu, Chen, Elberling, 2024). Ottmar Edenhofer of the Potsdam Institute for Climate Impact Research, in turn, is researching strategies to reduce greenhouse gas emissions (Kalkuhl, Steckel, Edenhofer, 2020; Kalkuhl, Steckel, Montrone, Jakob, Peters, Edenhofer, 2019; Siegmeier, Mattauch, Edenhofer, 2018; Edenhofer, Seyboth, Creutzig, Schlömer, 2013). As co-chair of the Intergovernmental Panel on Climate Change (IPCC), he is actively involved in developing global sustainability strategies and indicators. All these researchers and their analyses constitute important contributions to understanding the importance of monitoring air quality and greenhouse gas emissions in the context of sustainable development.

It is important to note that while traditionally, GHGs have been analysed mainly in the context of climate change, there is a growing body of research highlighting their relationship with air quality and the importance of an integrated approach to improving air quality and reducing GHG emissions and their monitoring in the context of sustainable development (Sachs, 2021). Research points directly to the growing need to integrate the monitoring of air pollutants and GHG emissions as a key element for developing sustainable development strategies effectively (Nugroho, Basuki, Pratiwi, Savitri, Supangat, Putra, Purwanto, Wahyuningrum, Adi, Setiawan, Nandini, Cahyono, Auliyani, Nada, Pratiwi, Hasani, 2025). Indeed, links and feedback between climate change and air pollution have been confirmed, and complex interactions between greenhouse gas emissions and air quality have been demonstrated. Research shows that air quality monitoring systems should also include GHG emissions to effectively support implementing environmental policies and the achievement of SDG targets (Im, Geels, Hanninen, Kukkonen, Rao, Ruuhela, Sofiev, Schaller, Hodnebrog, Sillmann, Schwingshackl, Christensen, Bojariu, Aunan, 2022). By monitoring these two aspects in an integrated manner, it is not only possible to keep track of countries' progress on an ongoing basis, but also to accurately identify areas in need of intensified action to improve air quality (Sena, Costa, Leitão, Silva, 2024).

In this context, it becomes important to monitor air quality, including greenhouse gas emissions, in the countries that are working towards sustainable development goals, and thus to analyse the changes taking place in these countries. This article attempts to assess the changes taking place in CEE countries in terms of air quality in the light of selected environmental variables of its monitoring and the classification of these countries in comparison with other EU countries, filling the research gap that exists in this respect.

Sustainability Development Indicators and air quality

International agreements have addressed various aspects of climate change and climate action, also becoming a reference point for corresponding action within the EU. Mention should be made here of the document: United Nations Framework Convention on Climate Change, adopted in 1992, which constitutes an international agreement to combat climate change. As stated, its overarching objective is *stabilization of green house gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system* (United Nations, 1992). The Montreal Protocol, signed in 1987 and which entered into force in 1989, is another international agreement dealing with environmental aspects, but focusing on the protection of the stratospheric ozone layer and aims to control and limit emissions of ozone-depleting substances, in terms of production as well as consumption. It covered practical tasks to be implemented. The protocol has evolved, having been revised several times, with the most recent amendment, the Kigali Amendment, to phase out hydrofluorocarbons (United Nations, 1997; UNEP, 2020). In contrast, the Paris Agreement, a global response to the threat of climate change, entered into force in 2016, whose provisions are addressed to all countries. It aims at *holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1,5°C above pre-industrial levels* (United Nations, 2015).

The Kyoto Protocol, on the other hand, is addressed to developed countries, was negotiated in 1997, and constitutes a commitment from industrialised countries to reduce greenhouse gases (UNFCC, 1997).

Following international agreements focusing on climate change and climate action, the European Union has undertaken a number of activities in this area. Caring for air quality, which is a major environmental challenge, is therefore at the centre of the EU's attention. To this end, legislation is being developed at the EU level, the most important of which is that on air quality. EU Member States are also making pollutant emission reduction commitments set out in the legislative acts they adopt. The European Green Deal sets the achievement of zero net greenhouse gas emissions in the EU by 2050. It emphasises that ensuring a non-toxic environment requires preventing new pollution, also reducing and removing the existing pollution, and taking appropriate action in this regard. Monitoring, information, prevention and remediation of pollutants, including air pollution, was considered important (European Council, Council of EU, 2024; European Commission, 2019). Following these indications, the Communication titled *The Road to a Healthy Planet for All*, adopted in May 2021, outlined the EU's roadmap for the elimination of air, water, and soil pollution, identifying key 2030 targets for accelerating pollution reduction. The key actions for 2021–2024 were identified, complementing those included in other European Green Deal initiatives (European Commission, 2021a; European Commission, 2021b).

The concentration of pollutants in ambient air can be monitored based on the awareness of parameters, e.g., qualitative and quantitative characteristics of emission sources, variability in atmospheric conditions and a representative location for the site and an adequate number of measurement points to ensure a reliable assessment of the variation in pollutant concentrations. Both deterministic methods, which analyse the relationship between emitters and receptors, and statistical methods, which use the results of pollutant concentrations to determine the receptor-source relationship, are used to assess pollutant concentrations. Statistical methods allow inference under conditions of incomplete information, which is an important advantage in real-world conditions (Mazur, Michałowski, 2001). Monitoring of sustainable development, including air quality, in the European Union is based on a system of indicators. Eurostat measures progress towards sustainable development priorities through Sustainable Development Indicators (SDIs). Every year, it publishes a report that assesses progress at the EU and individual Member State levels, including CEE. The SDIs cover areas such as economic and social development, sustainable consumption and production, public health, climate change and energy, sustainable transport, natural resources, among others. These categories form a structure currently including 102 indicators.

Quantifying the Sustainable Development Goals (SDGs) makes it possible to assess their initial status, set targets and monitor progress. SDIs databases make it possible to diagnose the current state and assess changes over time for the EU as a whole and for individual Member States, including SEE. Currently, the environmental priorities of the Sustainable Development Strategy in the EU are monitored on the basis of indicators corresponding to the 13th SDG and include the following indicators (European Commission, 2024):

- net greenhouse gas emissions,
- net greenhouse gas emissions from land use, land use change, and forestry (LULUCF),
- average CO2 emissions per km from new cars,
- climate-related economic losses,
- contribution to the international commitment of USD 100 billion for climate-related expending,
- green bond issuance.

Air quality in the Central and Eastern European countries in 2010–2020

In the CEE countries, GHG emissions to the atmosphere gradually decreased between 2010 and 2020. In 2010, Bulgaria, Estonia, and Poland were the largest emitters (Table 1), and in the analysed period, of these three countries, Poland's greenhouse gas emission reduction dynamics were relatively high. Indeed, there was a 36% reduction in 2020. However, the greatest progress in GHG reduction was recorded in Estonia.

Table 1. *Greenhouse gases emissions in 2010–2020* (grams per euro, current prices)*

Countries	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Dynamic indicators 2020/2010
Bulgaria	1 691.44	1 702.64	1 546.42	1 427.38	1 480.15	1 474.34	1 334.31	1 292.75	1 113.5	986.51	867.76	51.3
Czechia	814.83	767.26	751.98	735.52	732.5	681.16	662.66	595.88	551.25	485.96	456.46	56.02
Estonia	1 592.34	1 382.53	1 266.92	1 328.35	1 185.79	964.22	1 003.08	978.06	854.04	567.73	443.96	27.88
Croatia	565.76	561.9	536.3	517.02	505.96	496.56	474.36	469.97	423.66	407.15	426.25	75.34
Cyprus	473.43	427.48	400.85	392.17	433.12	411.26	412.5	402.95	382.03	344.47	349.34	73.79
Latvia	705.77	604.53	525.32	498.32	476.09	471.37	454.19	432.47	421.83	404.63	353.47	50.08
Lithuania	732.84	681.74	629.19	561.96	562.89	574.03	542.23	523.87	501.65	475.07	504.11	68.79
Hungary	647.23	632.1	595.44	565.17	552.55	543.71	522.97	498.21	471.7	427.15	430.36	66.49
Malta	484.95	486.58	480.38	397.38	364.55	237.54	193.46	186.81	176.57	169.38	165.13	34.05
Poland	1 142.95	1 101.05	1 042.5	1 024.33	954.86	904.73	941.31	896.67	840.19	752.91	731.52	64.003
Romania	957.03	957.09	943.57	813.04	761.44	714.06	659.52	601.47	553.86	492.82	478.22	49.97
Slovenia	477.77	459.8	450.66	442.25	385.21	380.19	379.04	358.82	342.58	320.69	315.27	65.99
Slovakia	629.86	606.16	543.55	508.17	471.53	463.91	464.57	459.61	436.49	390.82	360.84	57.29

**CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent*

Source: Eurostat database and own elaboration.

Improving air quality is also supported by the increasing use of renewable energy sources. Also in this area, there was an improvement in the rate in all CEE countries between 2010 and 2020. In 2020, the highest share of renewable energy use was recorded in Latvia (42.1%), Croatia (30.1%) and Estonia (31%). Noteworthy is the high growth rate of the share of renewable energy use in Malta from 0.979% in 2010 to 10.7% in 2020 (Table 2).

Table 2. *Share of renewable energy in gross final energy consumption by sector in 2010–2020 (in percentages)*

Countries	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bulgaria	-110.8	-80.5	-75.9	-65.9	-77.2	-72.8	-89.0	-88.4	-90.5	-90.0	-86.5
Czechia	-89.3	-93.3	-94.8	-86.6	-85.6	-84.7	-73.5	-52.2	17.8	104.4	161.9
Estonia	-106.7	-106.4	-78.2	-47.7	-37.1	-46.9	-46.2	-27.9	-31.7	-7.4	28.6
Croatia	-121.4	-99.1	-91.4	-103.7	-101.4	-95.9	-95.6	-86.2	-92.3	-94.6	-93.8
Cyprus	-31.9	-36.4	-35.5	-38.2	-38.4	-38.6	1.8	-39.0	-37.7	-37.7	-37.7
Latvia	-29.1	-35.4	-56.5	-36.8	22.6	2.9	-25.5	-48.0	-8.9	-37.3	10.0
Lithuania	-159.7	-162.3	-153.2	-144.0	-129.9	-120.2	-109.2	-99.5	-97.3	-81.2	-82.8
Hungary	-47.5	-43.8	-49.4	-41.4	-52.5	-60.8	-48.3	-55.0	-47.7	-52.8	-73.4
Malta	35.4	-6.3	-5.7	-5.1	-13.3	-12.0	-12.0	-6.0	-3.5	-4.4	-7.0
Poland	-113.1	-130.7	-131.2	-138.8	-113.8	-98.7	-122.7	-126.0	-124.1	-65.2	-67.2
Romania	-118.4	-119.1	-129.4	-130.8	-142.9	-138.3	-146.4	-136.4	-124.6	-119.5	-138.0
Slovenia	-353.1	-348.2	-343.3	-266.7	30.2	35.2	43.1	49.8	52.4	-241.1	-233.6
Slovakia	-135.6	-142.2	-162.0	-175.8	-135.5	-145.8	-147.5	-145.2	-126.7	-140.5	-178.4

Source: Eurostat database and own elaboration.

It should be emphasised that it is important to maintain a balance between greenhouse gas emissions and removals. Land use, land use change and forestry *are related to land use, land use change and forestry* (Ministerstwo Rolnictwa i Rozwoju Wsi, 2024). LULUCF's GHG emissions and removals balances in 2010 were negative except for Malta, and in, 2020 negative balances applied to all SEE countries except the Czech Republic, Estonia, and Latvia. Slovenia also had the largest negative balance in that year (Table 3).

Table 3. *Net greenhouse gas emissions of the Land use, Land use change and Forestry (LULUCF) in 2010–2020 (tonnes per square kilometre)*

Countries	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bulgaria	-110.8	-80.5	-75.9	-65.9	-77.2	-72.8	-89.0	-88.4	-90.5	-90.0	-86.5
Czechia	-89.3	-93.3	-94.8	-86.6	-85.6	-84.7	-73.5	-52.2	17.8	104.4	161.9
Estonia	-106.7	-106.4	-78.2	-47.7	-37.1	-46.9	-46.2	-27.9	-31.7	-7.4	28.6
Croatia	-121.4	-99.1	-91.4	-103.7	-101.4	-95.9	-95.6	-86.2	-92.3	-94.6	-93.8
Cyprus	-31.9	-36.4	-35.5	-38.2	-38.4	-38.6	1.8	-39.0	-37.7	-37.7	-37.7
Latvia	-29.1	-35.4	-56.5	-36.8	22.6	2.9	-25.5	-48.0	-8.9	-37.3	10.0
Lithuania	-159.7	-162.3	-153.2	-144.0	-129.9	-120.2	-109.2	-99.5	-97.3	-81.2	-82.8
Hungary	-47.5	-43.8	-49.4	-41.4	-52.5	-60.8	-48.3	-55.0	-47.7	-52.8	-73.4
Malta	35.4	-6.3	-5.7	-5.1	-13.3	-12.0	-12.0	-6.0	-3.5	-4.4	-7.0
Poland	-113.1	-130.7	-131.2	-138.8	-113.8	-98.7	-122.7	-126.0	-124.1	-65.2	-67.2
Romania	-118.4	-119.1	-129.4	-130.8	-142.9	-138.3	-146.4	-136.4	-124.6	-119.5	-138.0
Slovenia	-353.1	-348.2	-343.3	-266.7	30.2	35.2	43.1	49.8	52.4	-241.1	-233.6
Slovakia	-135.6	-142.2	-162.0	-175.8	-135.5	-145.8	-147.5	-145.2	-126.7	-140.5	-178.4

Source: Eurostat database and own elaboration.

There has been a gradual improvement in air quality indicators in the new EU Member States between 2010 and 2020, which is also the result of actions and investments made in this area. In this context, it becomes expedient to identify the situation of these countries in terms of air quality in comparison with other EU countries.

Air quality in Central and Eastern European countries compared to other EU countries in 2010–2020

Air quality in EU countries, as a multidimensional and complex phenomenon, can be described simultaneously by several selected characteristics using statistical methods of multivariate analysis. They allow grouping of countries that are similar due to the adopted set of variables and also identify those countries that are different[1].

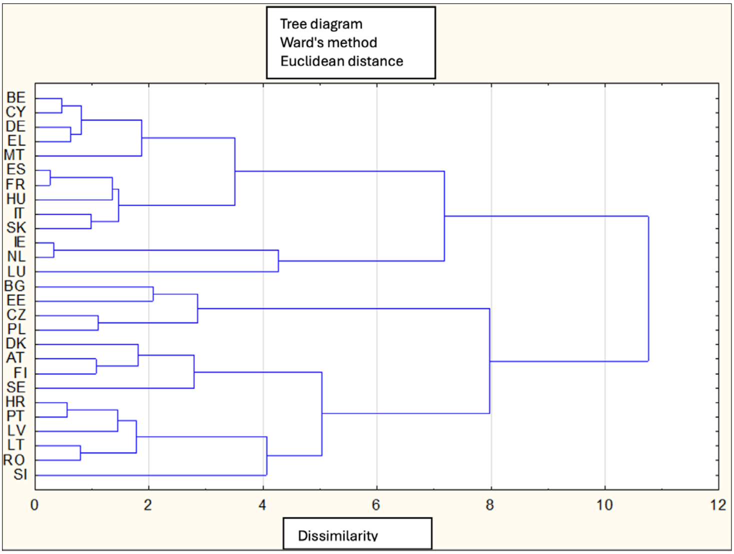
The analysis aims to identify groups of EU countries that are similar in terms of air quality and to identify the changes that have taken place in the countries, accounting for it. In particular, the situation of the new EU Member States in this aspect will be presented. To group EU countries by similarity in terms of air quality, an agglomeration grouping method was used, known as Ward's method[2]. From a set of potential diagnostic variables, four diagnostic variables characterising different aspects of air quality were selected, reflecting them relatively well. Indicators for air quality monitoring related to SDG target 13 were also considered. Data were obtained from the Eurostat database. The selection of diagnostic variables was based on substantive and formal criteria, including data availability for the selected group of countries in 2010 and 2020. The procedure for establishing the diagnostic variables was as follows. Initially, five potential diagnostic variables reflecting selected aspects of air quality were adopted, but their number was reduced to four due to the availability of data for EU countries and taking into account the adopted period covered by the analysis, i.e., between 2010 and 2020. They were also subjected to verification using statistical procedures, i.e. coefficient of variation, correlation with other variables. The final variables adopted for 2010 and 2020 are as follows:

- X1 – Greenhouse gases emissions (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent) grams per euro, current prices,
- X2 – Share of renewable energy in gross final energy consumption by sector (in percentage),
- X3 – Net greenhouse gas emissions total (excluding LULUCF and memo items, including international aviation), tonnes per capita,

- X4 – Net greenhouse gas emissions of the Land use, Land use change and Forestry (LULUCF) sector, tonnes per square kilometre.

The results of the clustering, presented as a dendrogram, are as follows (Figure 1).

Figure 1. *Classification of EU-27 countries by air quality in 2010*



Source: own elaboration.

The results of the grouping made it possible to identify four groups of countries, similar in the light of the diagnostic variables adopted in 2010. The new EU Member States, i.e., Poland, the Czech Republic, Hungary, Slovakia, Slovenia, Lithuania, Latvia, Estonia, Malta, Cyprus, Croatia, Bulgaria and Romania were classified into three groups. The first includes Bulgaria, the Czech Republic, Estonia, Poland. The second group includes Belgium, Germany, Greece, Spain, France, Italy, Cyprus, Hungary, Malta and Slovakia: a total of 10 countries. The third group consists of Ireland, Luxembourg and the Netherlands, while the fourth group – of 10 countries: Denmark, Croatia, Latvia, Lithuania, Austria, Portugal, Romania, Slovenia, Finland and Sweden.

The average values of the variables for each group of EU-27 countries in 2010 are presented in Table 4. Group 1, which includes the new EU Member States including Poland, is characterised by the highest average value of indicator X1, a relatively high average size of indicator X2, and at the same time, the highest negative net LULUCF balance (X4). Therefore, this group of countries can be identified as those in which the problem of GHG emissions was urgent to solve. In contrast, for group 4, which includes as many as five new EU Member States, as well as the Scandinavian countries, Austria and Portugal, the average X2 value is the highest, the lowest average X3 value, high X4 value, thus including countries performing relatively well in the area of air quality.

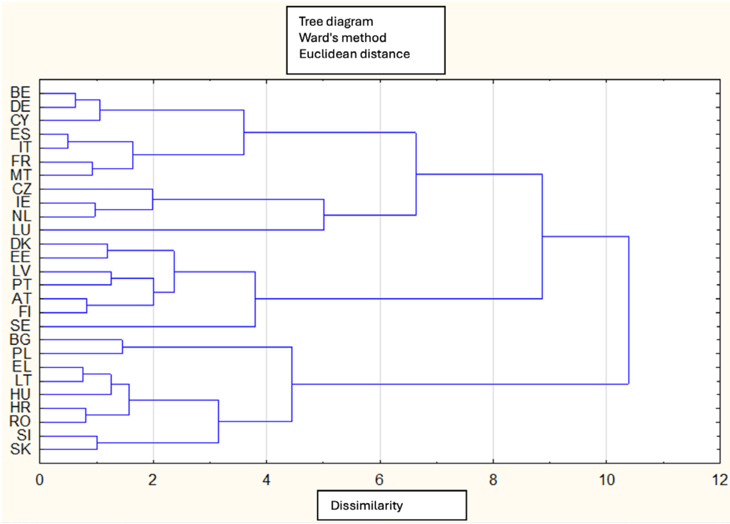
Table 4. *Average values of air quality variables for each group of EU27 countries in 2010*

Group	X1	X2	X3	X4
1	1310.39	14.57	12.10	-104.98
2	422.63	9.62	9.59	-52.57
3	301.33	4.17	18.13	77.30
4	511.114	27.454	8.600	-102.610

Source: own elaboration.

In contrast, the analysis of air quality data for the EU-27 countries for 2020 allowed four groups of countries to be distinguished (Figure 2). In turn, Table 5 shows the average values of the diagnostic variables.

Figure 2. *Classification of EU-27 countries by air quality in 2020*



Source: own elaboration.

Table 5. *Average values of air quality variables for each group of EU27 countries in 2020*

Group	X1	X2	X3	X4
1	207.21	17.20	7.34	-40.96
2	257.67	39.78	7.04	-16.80
3	515.32	22.18	7.10	-109.30
4	238.73	14.79	12.38	56.40

Source: own elaboration.

The results of the grouping of countries when considering the data for 2020 indicate that it is in the countries classified in Group 3 that the GHG emissions problem should still be considered as significant. Group 3 includes nine countries (Bulgaria, Greece, Croatia, Lithuania, Hungary, Poland, Romania, Slovenia, Slovakia) i.e., apart from Greece, all new EU Member States. Nevertheless, the relatively high share of renewable energy (X3) and the high negative average magnitude of the X4 indicator indicate a positive transformation of air quality improvement measures taking place in this group of countries. Countries in Group 2 can be identified as those where significant action is being taken to improve air quality, as reflected in the values of the indicators included in the analysis. This group includes seven countries: three Scandinavian countries, Austria, and Portugal, and two new EU Member States: Estonia and Latvia.

Conclusions

Changes in the structure of the economy, such as the share of heavy industry or the service sector, can be inferred from the dynamics of GHG emissions. A change in the emission rate can also be indicative of changes in society, such as an increase in environmental awareness or a focus on knowledge – and innovation-based development. Reducing greenhouse gas emissions is therefore linked to the need for structural changes in the energy sector, transport, increased conservation and rationalisation of energy use, as well as the development of research and increased innovation. Contemporary climate protection programmes, including strategies to reduce greenhouse gas emissions, emphasise the integration of environmental objectives with economic and social aspects. It becomes important to monitor air quality, including greenhouse gas emissions, in the countries that are working towards sustainable development goals, and thus to analyse the changes taking place there. In this context, the monitoring of ambient air quality is at the centre of the EU's and Member States' attention through SDIs, measuring progress towards sustainable development goals. An analysis of air quality in the SEE countries for the period 2010–2020 showed that these countries are gradually reducing pollutant emissions and increasingly using renewable energy sources. Nevertheless, it is important for these countries to maintain a balance between GHG emissions and removals. On the other hand, the analysis of the situation of SEE countries in comparison with other EU countries showed that in 2020, the group of countries where the problem of GHG emissions should be considered significant included the new EU Member States (eight countries – Bulgaria, Croatia, Lithuania, Hungary, Poland, Romania, Slovenia, Slovakia) and Greece. In this context, taking more intensive action on air quality and its monitoring seems to be a priority.

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Endnotes

[1] More on the multivariate analysis in: (Balicki, 2009), (Panek, 2009).
[2] More in: (Balicki, 2009).