Article
Development and Structural Changes of Carbon Footprint in EU28

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Abstract: This paper examines the development of CO₂ emissions in individual countries of the European Union (EU28) for the period between 2000 and 2017. Carbon footprint is monitored in four basic economic sectors of the EU28 countries—energy, other industries, agriculture, and waste management. The purpose of this paper is to conduct a structural analysis of the percentage contribution of individual sectors while determining the average conversion of emissions in tonnes per capita for individual countries, subsequently identifying the tendencies in the development of the detected rates. A cluster analysis for the EU28 that demonstrate similar carbon footprint values in the examined economic areas is conducted for the findings. The partial aim of the paper is to perform a comparison of the monitored countries and detect whether the differences between those striving for decarbonisation are diminishing. The energy industry is the most significant contributor to emission levels. The index analysis indicates that the level of emissions throughout the EU28 in all the monitored sectors has decreased, predominantly in waste management (by 40%), which is followed by industry (17%), energy (by 16.2%), and agriculture (by 5%). The cluster analysis conducted for 2000 and 2017 has confirmed the convergence of the identified groups of the EU28. Individual clusters of the countries thus display minor differences and converge in general.

Keywords: CO₂ emission; industry; transport; agriculture; waste management; index analysis; growth rate; cluster analysis

1. Introduction

In recent years, there has been increased pressure to limit the temperature rise by 1.5 °C to the preindustrial level. This task requires a decrease in greenhouse gas emissions, which can be achieved only through global commitments at an entire state level. It is also necessary to emphasise that smaller units, such as regions, towns, entities, and individuals, need to be engaged in the large-scale decarbonisation.

According to Niamir et al. [1], households as the main “change agents” in the transformation process towards green economies play a crucial role in the reduction of global emissions. Individual measures, mainly when boosted by social dynamics, create a demand for green energy and influence investments in emerging energy technologies, which can contribute to limiting regional and national emissions.

The energy is currently produced primarily from coal (ca. 40%), natural gas (ca. 20%), nuclear energy in nuclear plants (ca. 16%), water in hydro power plants (7%), oil (ca. 7%) and merely 5% from renewable sources (wind, sun, geothermal, and others) [2].

According to Paroussos et al. [3], the transition to a low-carbon economy is a rather complicated and gradual process which, from a technical viewpoint, requires the participation of individual market participants, technological progress, and financial resources. To a certain degree, the application itself is dependent on the country’s ability to assimilate someone else’s knowledge as well as on other factors—energy system, access to capital, and other.
Richter et al. [4] state that diversion from coal is the main initiator of the transition to a low-carbon economy. The outcome of the study is the fact that the coalition of the major coal exporters would be the subject of corporate tax levied on this commodity in particular. This fiscal burden would increase tax revenues and would thus have an impact on the global coal consumption.

Industries contribute largely to the total emissions produced in the world, while economic growth also causes an increase in CO\textsubscript{2} emissions with a short-term and significant coefficient [5]. Bengochea-Morancho et al. [6] have investigated the correlation between economic growth and CO\textsubscript{2} emission levels in the European Union. The results indicate significant differences between industrial and other countries. The conclusions suggest a relatively important idea, namely that the decrease in emissions should be achieved by considering the specific economic situation of individual member states. The steel industry alone emits approximately 3.5% of the total greenhouse gases [7].

According to Marrero et al. [8], transport represents another significant producer of CO\textsubscript{2} emissions. Over the past decades, there has been a substantial increase in the number of diesel automobiles in the EU. The results imply rather interesting information, for instance, a tax policy based on carbon content in fuel (higher in diesel) would be more effective than tax based on fuel efficiency while, in addition, other external expenses are higher for diesel than for petrol. Recently, the development of a market with “clean vehicles” is the subject of experts’ discussions. However, these changes are insufficient and, furthermore, they relate to emission scandals.

Hag and Weiss [9] mention that consumers are affected by information asymmetry since the information about the level of automobile emissions is based on laboratory tests. Fontaras et al. [10] add that the level of emissions in real traffic differs considerably from those tested in laboratory conditions. Ziegler [11] or Hackbarth and Madlener [12] present additional factors that limit the development of the market with “clean vehicles”, such as unavailability of filling stations for alternative fuels, long charging periods for electric vehicles, or a more limited number of models available than is common for conventional automobiles. Hulshof and Mulder [13] state that, firstly, a customer must understand the necessity to implement new measures that result in a decrease in emissions in personal transportation, which will be reflected in their internal willingness to pay. Some authors, for example, Kuwahara et al. [14] focus on the development of intelligent transport systems which, thanks to better traffic flow and regulation, will decrease the total emissions.

According to Paustian et al. [15] agriculture is another significant source of CO\textsubscript{2} emissions. The agricultural land amounts to 1.7 billion hectares. The results suggest that soils have a limited capacity to store carbon, carbon absorbed in the soil could be discharged into the atmosphere unless proper management is maintained, and fossil inputs within agricultural activities must also be added to the total level of CO\textsubscript{2} from agriculture. Sauerbeck [16] presents possibilities to save CO\textsubscript{2} emissions, for example, by reducing soil tillage, optimizing fertilizer efficiency, and by enhancing irrigation and solar drying. These measures could contribute to a decrease in CO\textsubscript{2} emissions proportionally by 0.01–0.05 Gt of carbon per year (which represents merely 1% of the current state of fossil fuel CO\textsubscript{2} emissions). Harmsen et al. [17] mention that due to the limited potential for reduction, it is assumed that, in mitigating scenarios, agricultural CH\textsubscript{4} emissions will become an increasingly more dominant contributor to the total anthropogenic CH\textsubscript{4} emissions. In this regard, the enteric fermentation of ruminants is by far the most serious problem, which has been confirmed by Slaboch and Hálová [18] who state that farm animals and their numbers have a profound impact on the total emissions in agriculture. Increasing the proportion of renewable energy sources is another alternative. During the recent years, the support for renewable sources in the EU has grown substantially. Slaboch and Hálová [19] state that based on the results of the dynamic linear regression model, it could be concluded that every additional functional biogas station decreases CO\textsubscript{2} emissions the following year.

According to Jung and Park [20], the harmonization of economic development strategies and respect for the environment are essential for sustainable development. In terms
of a strategy, the integration of industrial policies and programs for enhancing energy efficiency as well as the accelerated replacement of fuels with low-carbon alternatives are necessary. Fallahi [21] adds that understanding the characteristics of CO₂ emissions is another important factor in suggesting and implementing policies against climate change. The results suggest that, regardless of the aggregation level, CO₂ emissions are highly persistent and nonstationary, which implies that even a temporary shock will have a permanent impact on CO₂ emissions. Wang [22] states that a focus on the countries experiencing considerable growth in both their economy and carbon dioxide emissions will be a priority in combating global warming.

By concluding the Paris Agreement about climate, the signatories have committed to decreasing CO₂ emissions before 2030 by 40% in comparison with the level in 1990. Furthermore, the European Commission has designed a strategy to achieve a climatically neutral economy. The conducted studies predominantly analyse the selected sectors which produce most greenhouse gases or their types. For this reason, the authors have decided to focus more comprehensively on the development of CO₂ emissions equivalent in individual sectors and in the EU28 countries and compare the progress in the period between 2000 and 2017. This also concerns a longer assessment period in which the commitment of the countries to reduce emissions deriving from partial legislative measures should be demonstrated.

The aim of this paper is to analyse the composition of CO₂ emission equivalent for individual European countries (EU28) and compare its level per population. Subsequently, based on the partial results, the EU28 countries will be ranked according to their tendency to achieve the required reduction of CO₂ emissions. The analysis was conducted using descriptive statistics as well as k-means analysis, which enables object classification according to similar features. In this case, this concerns individual EU28 countries characterised by different production of CO₂ emissions according to economic sectors. Furthermore, a cluster analysis for 2000 and 2017 was conducted. This study can thus contribute to the conception of policy convergence with regard to reducing emissions by the EU, in that it determines the differences between the countries and assesses the progress of greenhouse gas production in individual EU countries in an aggregated form according to economic sectors.

2. Materials and Methods

In individual countries of EU28, the data on CO₂ emissions have been obtained from Eurostat—these concern consistent data recorded for the period 2000–2017. The information on emissions is divided into the following four categories according to the economic sector from which it originates: energy, industry, agriculture, and waste management.

To accomplish the objective, the following research questions have been formulated:

RQ1: Is there a reduction in the total emissions of EU countries during the period between 2000 and 2017 by more than 10%? Is the total reduction of CO₂ emissions evident in all the EU28 countries? Descriptive statistics and measures of dynamics are used to respond to the question.

RQ2: Which sector contributes most to the total of CO₂ emissions in individual EU28 countries? The question is assessed based on the contribution of individual sectors to the total emissions of the EU28 countries.

RQ3: Are there significant differences between the EU28 countries in the structure of emissions from individual sectors? Which countries within the structure are similar? The question is assessed using cluster analysis for the first and the final year of the time series used.

Basic descriptive statistical tools have been used to process the data, namely, growth coefficient, average growth coefficient, relative growth, average relative growth, base coefficient and emissions per capita [23]. To illustrate the indicators clearly, the tables...
present even years solely. The growth coefficient $k_t$ for individual variables $y$ in time $t = 2 \ldots T$ is computed using the following formula:

$$k_t = \frac{y_t}{y_{t-1}}$$

(1)

Multiplication of the growth coefficient by 100 provides information about the percentage rate of the value in time $t$ at which the value in time $t - 1$ has increased.

The average growth coefficient is estimated as follows:

$$\bar{k} = \sqrt[\tau]{k_1 \times k_2 \times k_3 \ldots \times k_T} = \sqrt[\tau]{\frac{y_2}{y_1} \times \frac{y_3}{y_2} \ldots \times \frac{y_T}{y_{T-1}}} = \sqrt[\tau-1]{\frac{y_T}{y_1}}$$

(2)

Since the interpretation of the growth coefficient is rather uncomfortable, it is suitable to use the dynamics indicator to determine the increase as, after its multiplication by 100, it provides information about the quantitative change in % in time $t$ in comparison with time $t - 1$, which concerns a relative increase (relative growth or growth rate).

$$\partial_t = \frac{\Delta y_t}{y_{t-1}} = \frac{y_t - y_{t-1}}{y_{t-1}} = \frac{y_t}{y_{t-1}} - 1 = k_t - 1$$

(3)

Its average value can be quantified as follows:

$$\bar{\partial} = (\bar{k} - 1)$$

(4)

Tables 1–4 assess the contribution of individual sectors to the total CO$_2$ emissions of the EU28 countries. The calculation was performed based on the EUROSTAT data. Table 1 shows the contribution of the energy sector to the total CO$_2$ emissions, while Table 2 illustrates the contribution of the industrial sector, Table 3 the contribution of the agricultural sector, and Table 4 the contribution of emissions produced by waste management. The average in the analysed period is calculated as the average contribution of a particular sector to the total emissions. Furthermore, the average growth coefficient examining the trend in the development of the contribution of a particular sector to the total emissions is calculated—if the indicator is lower than 100%, there is a decrease in the contribution of the sector to the total emissions. In contrast, if it exceeds 100%, there is an increase in the contribution of the sector to the total emissions. The indicator is calculated based on chain indexes (growth coefficient) during the analysed period. The final indicator included in the table concerns emissions in individual sectors per capita which enables better comparison of the results of differently sized EU28 countries in terms of their population, thus it is a dynamic indicator reflecting population changes in the analysed period along with the development of CO$_2$ emissions in a particular sector.

Subsequently, map clusters are created for the examined sectors based on emission values from individual sectors per capita. The division of the EU28 countries itself was made based on K-means clusters, which is a non-hierarchical method. In this case, the number of clusters was set to 5 and determined with regard to the previous studies, for example, by Tutak and Brodny [24,25]. K-means clustering was conducted using the Statistica program—multidimensional analysis.

The goal of the k-means algorithm is to detect the optimum “partition” for dividing a number of objects into k clusters. This procedure will shift objects from one cluster to another with the goal to minimize the within-cluster variance and maximize the between-cluster variance. The algorithm of the k-means method typically requires all the analysed variables to be quantitative. The similarity between the examined cases (in this case between the EU28 member states) is therefore measured using the distance function.
### Table 1. Contribution of energy to total emissions including descriptive statistics (%), tonnes.

| GEO/TIME | 2000  | 2002  | 2004  | 2006  | 2008  | 2010  | 2012  | 2014  | 2016  | 2017  | Average | Average Gr. Coef. | Emissions Per Capita in Tonnes (2017) |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|-------------------|-------------------------------------|
| Belgium  | 68.7  | 70.3  | 70.4  | 70.9  | 70.9  | 72.0  | 71.4  | 69.7  | 69.9  | 69.7  | 70.6    | 98.59%             | 7.33                               |
| Bulgaria | 68.2  | 70.5  | 70.3  | 71.9  | 73.6  | 75.4  | 75.6  | 72.7  | 70.9  | 71.9  | 72.5    | 100.53%            | 6.28                               |
| Czechia  | 81.5  | 81.6  | 80.6  | 80.7  | 79.4  | 79.9  | 78.8  | 76.5  | 76.6  | 76.2  | 79.5    | 98.77%             | 9.35                               |
| Denmark  | 74.0  | 74.8  | 75.1  | 77.2  | 74.6  | 75.5  | 70.9  | 69.3  | 68.6  | 66.9  | 73.2    | 97.34%             | 5.88                               |
| Germany  | 81.7  | 82.7  | 82.1  | 82.1  | 81.9  | 82.9  | 82.6  | 82.1  | 82.2  | 81.8  | 82.2    | 99.25%             | 9.28                               |
| Estonia  | 85.9  | 87.0  | 86.9  | 86.2  | 85.6  | 88.9  | 86.0  | 87.8  | 88.3  | 88.0  | 87.0    | 101.26%            | 14.09                              |
| Ireland  | 60.4  | 61.3  | 62.5  | 63.1  | 64.5  | 63.7  | 62.3  | 59.1  | 59.4  | 57.6  | 61.7    | 99.15%             | 7.68                               |
| Greece   | 75.0  | 76.2  | 76.5  | 78.3  | 78.1  | 76.9  | 72.9  | 70.5  | 70.9  | 75.8  | 98.13%             | 6.51                               |
| Spain    | 73.0  | 75.1  | 75.3  | 74.9  | 74.1  | 71.8  | 72.8  | 70.3  | 71.3  | 72.5  | 73.3    | 99.34%             | 5.56                               |
| France   | 69.5  | 69.7  | 70.3  | 70.1  | 69.2  | 69.7  | 69.0  | 66.9  | 67.9  | 67.9  | 69.1    | 98.91%             | 4.90                               |
| Croatia  | 70.0  | 72.1  | 71.2  | 70.7  | 69.7  | 69.6  | 68.8  | 67.8  | 68.5  | 68.1  | 70.1    | 99.70%             | 4.18                               |
| Italy    | 81.7  | 81.8  | 81.6  | 81.8  | 81.3  | 80.5  | 79.3  | 79.2  | 78.8  | 80.8  | 98.35%             | 5.71                               |
| Cyprus   | 69.2  | 67.7  | 69.1  | 70.4  | 71.7  | 72.8  | 71.5  | 66.2  | 67.3  | 66.5  | 69.4    | 100.22%            | 7.74                               |
| Latvia   | 69.2  | 69.5  | 70.0  | 70.3  | 68.7  | 66.8  | 62.1  | 61.2  | 62.2  | 61.6  | 66.4    | 99.93%             | 3.71                               |
| Lithuania| 55.2  | 55.6  | 55.9  | 56.3  | 53.8  | 61.7  | 54.6  | 54.9  | 55.4  | 54.7  | 55.9    | 100.28%            | 3.98                               |
| Luxembourg| 76.1  | 78.1  | 80.2  | 80.7  | 79.3  | 79.8  | 80.8  | 78.3  | 74.6  | 73.6  | 78.5    | 100.48%            | 14.86                              |
| Hungary  | 74.0  | 74.6  | 74.0  | 73.6  | 74.3  | 74.3  | 72.7  | 70.5  | 72.0  | 71.6  | 73.3    | 99.01%             | 4.71                               |
| Malta    | 81.9  | 82.7  | 82.4  | 80.8  | 82.3  | 79.0  | 79.7  | 75.6  | 62.2  | 62.6  | 77.9    | 97.39%             | 3.51                               |
| The Netherlands | 72.9 | 75.5 | 76.7 | 76.4 | 78.8 | 80.0 | 79.0 | 78.3 | 78.5 | 78.0 | 77.5 | 99.75% | 9.38 |
| Austria  | 67.5  | 69.4  | 71.4  | 69.6  | 67.3  | 68.6  | 67.4  | 65.7  | 66.2  | 66.6  | 68.3    | 100.09%            | 6.41                               |
| Poland   | 81.3  | 82.0  | 81.9  | 81.8  | 81.1  | 82.5  | 81.9  | 80.8  | 82.0  | 82.2  | 81.7    | 100.33%            | 9.01                               |
| Portugal | 72.3  | 73.6  | 71.9  | 71.5  | 69.1  | 68.2  | 68.2  | 65.9  | 65.0  | 68.8  | 69.9    | 99.00%             | 4.97                               |
| Romania  | 69.6  | 70.3  | 67.9  | 68.1  | 69.8  | 69.2  | 70.1  | 67.7  | 66.4  | 65.8  | 68.7    | 98.37%             | 3.85                               |
| Slovenia | 79.6  | 80.1  | 80.4  | 80.4  | 82.3  | 82.9  | 82.4  | 79.4  | 80.3  | 79.9  | 80.8    | 99.50%             | 6.78                               |
| Slovakia | 74.0  | 71.8  | 71.1  | 70.4  | 70.2  | 70.9  | 69.3  | 67.2  | 67.3  | 67.7  | 70.5    | 98.75%             | 5.42                               |
| Finland  | 75.5  | 78.2  | 78.8  | 78.4  | 74.4  | 77.9  | 73.9  | 73.0  | 72.3  | 71.4  | 75.6    | 98.42%             | 7.45                               |
| Sweden   | 69.7  | 71.0  | 71.0  | 69.9  | 69.3  | 71.0  | 69.4  | 67.7  | 66.5  | 66.1  | 69.5    | 98.29%             | 3.66                               |
| United Kingdom | 75.8 | 76.7 | 77.0 | 77.4 | 77.7 | 78.6 | 76.8 | 76.8 | 76.5 | 75.2 | 76.5 | 98.96% | 6.59 |

Source: own processing based on the data from Eurostat.
Table 2. Contribution of industry to total emissions including descriptive statistics (%, tonnes).

| GEO/TIME | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2017 | Average | Average gr. Coef. | Emissions Per Capita in Tonnes (2017) |
|----------|------|------|------|------|------|------|------|------|------|------|---------|-----------------|--------------------------------------|
| Belgium  | 18.4 | 17.8 | 18.1 | 17.6 | 17.0 | 15.7 | 15.4 | 16.8 | 16.9 | 16.5 | 16.8    | 97.87%           | 1.73                                 |
| Bulgaria | 12.1 | 10.7 | 11.3 | 11.5 | 10.6 | 7.3  | 7.8  | 8.7  | 10.2 | 10.3 | 9.9     | 99.31%           | 0.90                                 |
| Czechia  | 9.9  | 9.5  | 10.6 | 10.6 | 11.3 | 10.7 | 11.2 | 12.3 | 11.9 | 12.1 | 10.8    | 100.29%          | 1.48                                 |
| Denmark  | 5.1  | 4.7  | 4.5  | 3.7  | 3.8  | 2.9  | 3.8  | 3.8  | 3.8  | 4.0  | 4.0     | 96.48%           | 0.35                                 |
| Germany  | 7.3  | 6.9  | 7.6  | 7.4  | 7.4  | 6.5  | 6.5  | 6.7  | 6.7  | 6.9  | 7.0     | 98.89%           | 0.78                                 |
| Estonia  | 4.0  | 3.2  | 3.8  | 4.1  | 4.8  | 2.5  | 4.4  | 3.3  | 2.5  | 3.0  | 3.6     | 99.51%           | 0.49                                 |
| Ireland  | 6.8  | 6.1  | 5.2  | 5.4  | 5.0  | 3.9  | 4.3  | 4.9  | 5.2  | 5.4  | 5.1     | 98.16%           | 0.72                                 |
| Greece   | 11.8 | 11.4 | 10.9 | 9.4  | 9.6  | 9.7  | 9.8  | 12.1 | 13.2 | 12.9 | 10.8    | 99.00%           | 1.19                                 |
| Spain    | 10.5 | 9.2  | 9.5  | 10.6 | 10.8 | 10.9 | 9.8  | 10.7 | 8.9  | 7.9  | 9.9     | 97.71%           | 0.61                                 |
| France   | 9.5  | 9.5  | 9.4  | 9.3  | 8.9  | 8.9  | 8.9  | 9.4  | 9.1  | 9.1  | 9.2     | 98.81%           | 0.66                                 |
| Croatia  | 12.0 | 11.0 | 11.7 | 12.2 | 12.3 | 11.7 | 11.0 | 11.5 | 10.1 | 10.7 | 11.3    | 99.19%           | 0.66                                 |
| Italy    | 7.0  | 7.3  | 7.9  | 7.5  | 7.3  | 7.1  | 7.1  | 7.5  | 7.4  | 7.5  | 7.4     | 98.96%           | 0.54                                 |
| Cyprus   | 10.8 | 10.8 | 11.1 | 11.5 | 11.1 | 9.1  | 8.9  | 14.2 | 12.7 | 12.8 | 11.2    | 101.43%          | 1.49                                 |
| Latvia   | 2.2  | 2.5  | 2.9  | 3.1  | 3.4  | 5.5  | 7.4  | 7.2  | 5.6  | 6.2  | 4.5     | 106.94%          | 0.38                                 |
| Lithuania| 15.7 | 16.9 | 17.3 | 18.7 | 22.3 | 10.7 | 16.7 | 15.8 | 16.3 | 17.5 | 16.9    | 100.99%          | 1.28                                 |
| Luxembourg| 7.3 | 6.2  | 5.4  | 5.6  | 5.4  | 5.0  | 4.9  | 5.3  | 5.6  | 5.5  | 5.5     | 99.03%           | 1.12                                 |
| Hungary  | 11.1 | 10.2 | 11.2 | 11.6 | 10.2 | 9.8  | 10.1 | 11.1 | 10.4 | 11.2 | 10.7    | 99.21%           | 0.74                                 |
| Malta    | 0.5  | 0.8  | 1.2  | 2.7  | 3.6  | 4.7  | 6.0  | 7.6  | 11.7 | 12.3 | 4.7     | 119.67%          | 0.69                                 |
| The Netherlands | 9.5 | 7.8  | 7.2  | 7.5  | 5.3  | 5.3  | 5.3  | 5.3  | 5.1  | 5.4  | 6.4     | 96.13%           | 0.65                                 |
| Austria  | 17.8 | 17.3 | 15.9 | 17.6 | 19.4 | 18.3 | 19.0 | 20.4 | 20.0 | 20.3 | 18.3    | 100.96%          | 1.96                                 |
| Poland   | 6.0  | 5.4  | 6.3  | 6.7  | 7.1  | 6.1  | 6.6  | 7.2  | 6.6  | 6.5  | 6.4     | 100.75%          | 0.71                                 |
| Portugal | 9.1  | 8.7  | 9.8  | 9.9  | 11.2 | 10.7 | 9.9  | 11.6 | 10.5 | 10.5 | 10.1    | 100.10%          | 0.75                                 |
| Romania  | 13.1 | 12.9 | 14.4 | 14.1 | 12.3 | 11.4 | 10.7 | 10.6 | 11.1 | 11.4 | 12.1    | 97.88%           | 0.67                                 |
| Slovenia | 6.1  | 6.1  | 6.7  | 7.1  | 6.2  | 5.1  | 5.5  | 6.9  | 6.4  | 6.9  | 6.2     | 100.23%          | 0.58                                 |
| Slovakia | 17.4 | 19.6 | 20.9 | 21.5 | 21.5 | 20.5 | 20.9 | 22.0 | 22.2 | 22.2 | 20.5    | 100.68%          | 1.77                                 |
| Finland  | 8.4  | 7.7  | 8.2  | 8.5  | 10.5 | 8.0  | 9.3  | 9.3  | 10.2 | 10.3 | 9.0     | 99.94%           | 1.08                                 |
| Sweden   | 11.9 | 12.2 | 12.5 | 12.8 | 12.8 | 12.6 | 12.7 | 13.1 | 14.2 | 13.7 | 12.6    | 99.43%           | 0.76                                 |
| United Kingdom | 5.5 | 5.1  | 5.5  | 5.4  | 5.7  | 5.5  | 5.3  | 6.1  | 6.0  | 6.0  | 5.6     | 98.28%           | 0.46                                 |
| EU28     | 8.6  | 8.2  | 8.7  | 8.7  | 8.0  | 8.0  | 8.6  | 8.4  | 8.4  | 8.4  | 8.4     | 98.90%           | 0.74                                 |

Source: own processing based on the data from Eurostat.
Table 3. Contribution of agriculture to total emissions including descriptive statistics (%, tonnes).

| GEO/TIME | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2017 | Average | Average Gr. Coef. | Emissions Per Capita in Tonnes (2017) |
|----------|------|------|------|------|------|------|------|------|------|------|---------|------------------|-------------------------------------|
| Belgium  | 7.3  | 7.3  | 6.9  | 6.9  | 7.1  | 7.4  | 8.0  | 8.6  | 8.2  | 8.5  | 7.6     | 99.33%           | 0.89                                |
| Bulgaria | 8.7  | 8.6  | 8.6  | 7.8  | 7.6  | 8.9  | 8.5  | 10.5 | 11.0 | 10.6 | 8.8     | 101.37%          | 0.92                                |
| Czechia  | 5.6  | 5.7  | 5.4  | 5.1  | 5.4  | 5.2  | 5.6  | 6.2  | 6.5  | 6.5  | 5.7     | 100.03%          | 0.80                                |
| Denmark  | 15.6 | 15.5 | 15.2 | 13.9 | 15.8 | 16.0 | 18.7 | 19.8 | 20.1 | 21.1 | 16.9    | 99.67%           | 1.85                                |
| Germany  | 6.4  | 6.2  | 6.2  | 6.2  | 6.5  | 6.6  | 6.8  | 7.3  | 7.1  | 7.1  | 6.6     | 99.83%           | 0.80                                |
| Estonia  | 6.5  | 6.3  | 6.0  | 6.3  | 6.3  | 5.8  | 6.5  | 6.5  | 6.8  | 6.5  | 6.3     | 101.19%          | 1.05                                |
| Ireland  | 28.1 | 26.9 | 27.1 | 25.6 | 25.4 | 27.9 | 29.6 | 30.8 | 29.8 | 30.7 | 28.0    | 99.95%           | 4.09                                |
| Greece   | 7.1  | 7.1  | 6.8  | 6.6  | 6.5  | 7.3  | 7.4  | 7.8  | 8.3  | 7.9  | 7.2     | 99.10%           | 0.73                                |
| Spain    | 10.9 | 10.2 | 9.8  | 8.9  | 8.8  | 10.2 | 9.8  | 11.0 | 11.2 | 11.1 | 10.1    | 99.47%           | 0.85                                |
| France   | 14.6 | 14.3 | 13.8 | 13.7 | 14.5 | 14.5 | 15.1 | 16.4 | 15.9 | 15.8 | 14.7    | 99.52%           | 1.14                                |
| Croatia  | 12.0 | 11.3 | 11.3 | 11.0 | 11.2 | 10.9 | 11.6 | 11.2 | 11.4 | 11.2 | 11.2    | 99.43%           | 0.68                                |
| Italy    | 6.0  | 5.8  | 5.5  | 5.5  | 5.6  | 5.8  | 6.5  | 6.9  | 7.0  | 7.0  | 6.1     | 99.43%           | 0.51                                |
| Cyprus   | 6.0  | 6.5  | 5.8  | 5.3  | 4.7  | 5.2  | 5.3  | 5.0  | 5.0  | 5.0  | 5.4     | 99.35%           | 0.58                                |
| Latvia   | 21.3 | 21.0 | 20.4 | 19.7 | 20.1 | 19.6 | 22.1 | 23.5 | 23.8 | 23.7 | 21.5    | 101.26%          | 1.43                                |
| Lithuania| 20.8 | 19.6 | 19.2 | 18.0 | 17.3 | 20.5 | 20.4 | 22.6 | 21.9 | 21.2 | 20.1    | 100.45%          | 1.55                                |
| Luxembourg| 6.6 | 5.6  | 4.7  | 4.5  | 4.9  | 5.0  | 5.0  | 5.6  | 6.1  | 6.0  | 5.3     | 100.05%          | 1.20                                |
| Hungary  | 8.2  | 8.5  | 8.4  | 8.1  | 8.5  | 8.6  | 9.8  | 11.2 | 11.1 | 10.9 | 9.2     | 100.89%          | 0.72                                |
| Malta    | 2.5  | 2.5  | 2.4  | 2.3  | 2.2  | 2.1  | 1.9  | 2.1  | 2.9  | 2.5  | 2.3     | 98.99%           | 0.14                                |
| The Netherlands | 9.0 | 8.4  | 8.0  | 8.3  | 8.3  | 8.0  | 8.5  | 9.1  | 9.1  | 9.2  | 8.6     | 99.48%           | 1.11                                |
| Austria  | 9.1  | 8.3  | 7.6  | 7.6  | 8.1  | 8.2  | 8.7  | 9.2  | 9.0  | 8.6  | 8.4     | 99.90%           | 0.83                                |
| Poland   | 7.8  | 7.8  | 7.3  | 7.2  | 7.5  | 7.2  | 7.4  | 7.8  | 7.6  | 7.6  | 7.5     | 100.13%          | 0.84                                |
| Portugal | 8.9  | 8.2  | 8.0  | 8.1  | 8.6  | 9.3  | 9.7  | 10.1 | 9.8  | 9.3  | 8.9     | 99.49%           | 0.67                                |
| Romania  | 13.3 | 13.0 | 13.7 | 13.9 | 13.9 | 14.5 | 14.4 | 16.1 | 16.7 | 16.8 | 14.6    | 100.07%          | 0.98                                |
| Slovenia | 9.4  | 9.1  | 8.3  | 8.2  | 7.8  | 8.5  | 8.5  | 10.0 | 9.7  | 9.6  | 8.8     | 99.62%           | 0.82                                |
| Slovakia | 5.6  | 5.7  | 5.0  | 4.8  | 4.9  | 5.0  | 5.7  | 6.5  | 6.2  | 5.9  | 5.5     | 99.57%           | 0.47                                |
| Finland  | 9.2  | 8.4  | 7.8  | 7.8  | 8.9  | 8.6  | 10.0 | 10.8 | 10.9 | 11.3 | 9.3     | 99.96%           | 1.18                                |
| Sweden   | 11.0 | 10.3 | 10.0 | 10.6 | 10.7 | 10.3 | 11.3 | 12.5 | 12.4 | 13.0 | 11.1    | 99.54%           | 0.72                                |
| United Kingdom | 6.1 | 5.9  | 6.0  | 5.9  | 5.9  | 6.3  | 6.6  | 7.4  | 7.9  | 8.2  | 6.5     | 99.42%           | 0.63                                |
| EU28     | 8.7  | 8.5  | 8.3  | 8.1  | 8.4  | 8.6  | 9.0  | 9.8  | 9.8  | 9.8  | 8.8     | 99.71%           | 0.86                                |

Source: own processing based on the data from Eurostat.
Table 4. Contribution of waste management to total emissions including descriptive statistics (%), tonnes.

| GEO/TIME | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2017 | Average | Average Gr. Coef. Growth Rate | Emissions Per Capita Per Capita in Tonnes (2017) |
|----------|------|------|------|------|------|------|------|------|------|------|---------|-------------------------------|--------------------------------------------|
| Belgium  | 2.6  | 2.3  | 2.1  | 2.1  | 1.9  | 1.8  | 1.8  | 1.4  | 1.2  | 1.2  | 1.9     | 94.38%                          | 0.13                                       |
| Bulgaria | 10.7 | 9.6  | 9.1  | 8.0  | 7.3  | 7.5  | 7.2  | 7.3  | 6.8  | 6.1  | 8.0     | 96.97%                          | 0.53                                       |
| Czechia  | 2.6  | 2.8  | 2.8  | 2.9  | 3.1  | 3.5  | 3.8  | 4.2  | 4.3  | 4.4  | 3.4     | 102.28%                         | 0.53                                       |
| Denmark  | 2.1  | 2.1  | 1.7  | 1.7  | 1.9  | 1.8  | 2.0  | 2.0  | 2.1  | 2.2  | 2.0     | 98.40%                          | 0.20                                       |
| Germany  | 2.7  | 2.4  | 2.2  | 1.9  | 1.7  | 1.5  | 1.4  | 1.3  | 1.1  | 1.1  | 1.8     | 94.10%                          | 0.12                                       |
| Estonia  | 3.2  | 3.2  | 2.8  | 2.7  | 2.4  | 2.3  | 2.2  | 1.7  | 1.6  | 1.6  | 2.4     | 96.89%                          | 0.25                                       |
| Ireland  | 2.1  | 2.4  | 2.1  | 1.9  | 1.0  | 0.8  | 0.9  | 1.4  | 1.5  | 1.5  | 1.5     | 97.29%                          | 0.20                                       |
| Greece   | 4.1  | 3.5  | 3.5  | 3.7  | 3.5  | 3.9  | 4.4  | 4.8  | 4.7  | 3.9  | 3.9     | 99.15%                          | 0.43                                       |
| Spain    | 3.2  | 3.2  | 2.9  | 2.9  | 3.2  | 3.8  | 4.0  | 3.9  | 4.0  | 3.8  | 3.5     | 100.46%                         | 0.29                                       |
| France   | 3.9  | 3.9  | 3.8  | 3.8  | 3.9  | 3.9  | 3.6  | 3.6  | 3.8  | 3.6  | 3.8     | 98.60%                          | 0.26                                       |
| Croatia  | 5.1  | 5.0  | 5.1  | 5.3  | 5.8  | 6.7  | 7.4  | 8.0  | 8.5  | 8.2  | 6.3     | 102.66%                         | 0.50                                       |
| Italy    | 3.9  | 4.0  | 3.7  | 3.7  | 3.7  | 4.0  | 4.1  | 4.2  | 4.1  | 4.2  | 4.0     | 98.94%                          | 0.30                                       |
| Cyprus   | 5.0  | 5.0  | 4.8  | 4.7  | 4.5  | 4.8  | 5.4  | 5.9  | 5.8  | 5.6  | 5.1     | 101.18%                         | 0.66                                       |
| Latvia   | 6.5  | 6.2  | 5.4  | 5.2  | 5.3  | 5.1  | 5.3  | 5.2  | 5.2  | 4.8  | 5.4     | 98.82%                          | 0.29                                       |
| Lithuania| 7.9  | 7.6  | 7.0  | 6.2  | 5.8  | 6.4  | 5.6  | 5.4  | 5.5  | 5.0  | 6.3     | 97.71%                          | 0.36                                       |
| Luxembourg|1.0   | 0.9  | 0.7  | 0.7  | 0.8  | 0.7  | 0.7  | 0.7  | 0.7  | 0.8  | 0.8     | 98.74%                          | 0.14                                       |
| Hungary  | 5.7  | 5.8  | 5.6  | 5.6  | 5.9  | 6.3  | 6.5  | 6.5  | 6.2  | 5.4  | 5.2     | 98.68%                          | 0.34                                       |
| Malta    | 4.5  | 5.2  | 5.5  | 5.8  | 3.4  | 4.6  | 4.3  | 6.5  | 5.9  | 4.9  | 5.9     | 100.47%                         | 0.33                                       |
| Netherlands|4.3  | 3.9  | 3.4  | 2.7  | 2.4  | 2.1  | 2.0  | 1.8  | 1.6  | 1.5  | 2.6     | 93.41%                          | 0.18                                       |
| Austria  | 3.6  | 3.3  | 3.1  | 2.9  | 2.7  | 2.5  | 2.4  | 2.2  | 2.2  | 1.9  | 2.7     | 96.02%                          | 0.17                                       |
| Poland   | 4.7  | 4.6  | 4.3  | 4.0  | 3.9  | 3.7  | 3.7  | 3.7  | 3.4  | 3.1  | 4.0     | 97.94%                          | 0.34                                       |
| Portugal | 7.3  | 7.4  | 7.7  | 7.7  | 7.7  | 8.1  | 8.1  | 7.8  | 6.8  | 6.3  | 7.6     | 98.40%                          | 0.45                                       |
| Romania  | 3.7  | 3.6  | 3.7  | 3.6  | 3.7  | 4.5  | 4.4  | 5.0  | 5.1  | 5.1  | 4.2     | 100.62%                         | 0.30                                       |
| Slovenia | 4.5  | 4.4  | 4.3  | 3.9  | 3.2  | 3.2  | 3.2  | 3.2  | 3.2  | 3.2  | 3.7     | 97.44%                          | 0.27                                       |
| Slovakia | 2.9  | 2.9  | 2.9  | 3.0  | 3.0  | 3.4  | 4.0  | 3.9  | 3.9  | 3.9  | 3.3     | 101.00%                         | 0.31                                       |
| Finland  | 5.4  | 4.3  | 3.7  | 3.5  | 3.7  | 3.3  | 3.8  | 3.6  | 3.3  | 3.3  | 3.8     | 95.90%                          | 0.34                                       |
| Sweden   | 4.6  | 4.2  | 4.0  | 3.8  | 3.3  | 2.9  | 2.9  | 2.7  | 2.4  | 2.3  | 3.4     | 94.60%                          | 0.13                                       |
| United Kingdom | 8.5 | 8.2  | 7.1  | 6.4  | 5.6  | 4.6  | 4.3  | 3.8  | 3.9  | 4.0  | 5.7     | 93.59%                          | 0.31                                       |
| EU28     | 4.4  | 4.2  | 3.9  | 3.7  | 3.5  | 3.4  | 3.4  | 3.3  | 3.1  | 3.1  | 3.6     | 97.04%                          | 0.27                                       |

Source: own processing based on the data from Eurostat.
Furthermore, a cluster analysis for individual countries is conducted for years 2000 and 2017 to detect any deviations in individual clusters for the monitored period. The shift of the countries in the period within individual clusters represents the change in emissions in the examined sectors. The cluster analysis is conducted using the Statistica program and Ward’s method. The purpose of the cluster analysis is to classify various types of observations such that the final clusters in every class are homogeneous and, in contrast, that they differ from each other as much as possible. There are numerous methods to create such clusters which can generally be divided into hierarchical and non-hierarchical.

In the case of hierarchical agglomerative methods, the algorithm itself can be expressed in the following steps:

1- Match every object to one cluster (N objects, N clusters)
2- Calculate the distance between all the objects (for example, using a simple correlation, total correlation, average correlation, centroid correlation or Ward’s method)
3- Find the most similar pair of clusters and merge them into one (a reduced number of clusters is attained)
4- Calculate the distance between the new clusters and the remaining ones
5- Repeat steps 2, 3, 4 until all the objects are located in one cluster.

According to Hervada-Sala, C. and Eusebi J.B. [26], Ward’s cluster method is a hierarchical agglomerative method which can be described as follows. The existence of N elements that should cluster is assumed. N clusters comprising of one entity exactly initiate the process. By investigating the similarity matrix to identify the most similar cluster pair, the number of clusters gradually decreases until all the clusters have been consolidated. The goal of Ward’s method is to detect the two clusters in every phase whose consolidation provides a minimum increase of the total error sum of squares in the group (or the distance between the consolidated clusters’ centroids). The total error sum of squares within the group $V_T(K)$ at one stage with K groups, J variables, with N elements in each group, is defined as:

$$V_T(K) = \sum_{k=1}^{K} \left( \sum_{j=1}^{J} \left( \sum_{i=1}^{N_i} \left( \bar{x}_{jk}(i) \right)^2 \right) \right) \sum_{i=1}^{N_i} \bar{x}_{jk}(i) = \frac{1}{N_i} \sum_{i=1}^{N_i} \sum_{j=1}^{K} N_j = N$$

where $x_{ijk}$ is the value of j-th variable from i-th observation in k-th group, and $\bar{x}_{jk}(i)$ is the average value inside the group. Therefore, following the summation order, the first sum corresponds to variability inside the group for a given variable, the second adds all the variables, and the final is the total variability.

Each of the methods mentioned can lead to very different results based on an identical set of observations (step 2 in the algorithm). Ward’s method was used for the purpose of this paper, which has its advantages and disadvantages. It is effective when similarly sized clusters are expected and a set of observations does not contain outliers.

The agglomerative method employed does not directly determine the optimal number of clusters and therefore there are no objective rules. Analysing the directly acquired dendrogram in terms of the differences in the consecutive clusters is the simplest step. A high value of the difference then equates further distances in a cluster (a division could be made here) [27].

The objective is to identify the countries with similar composition of emissions per capita in the examined sectors that produce CO$_2$. Four variables thus enter the calculation — emission per capita for energy, industry, agriculture, and waste management. Eurostat data were used based on which the emission value of individual sectors per capita was calculated. All the EU28 states enter the research.

3. Results

Based on the data available from Eurostat, the total production of CO$_2$ emissions in the EU28 countries is slightly decreasing. Whereas 5.284 billion tonnes of CO$_2$ were produced in 2000, the total emissions in 2017 amounted to 4.481 billion tonnes, signifying a decrease
by 15.2%. This occurred despite the population growth in the EU28, which increased from 487.2 mil. in 2000 to 511.4 mil. in 2017 (representing a 5% increase). In 2017, the average value of emissions per capita in the EU28 countries amounted to 8.8 tonnes. Kijewska and Bluszcz [28] mention that in 2012 the average emission per capita in EU28 equated to nine tonnes. These results confirm the decreasing trend in the production of emissions in the CO\(_2\) equivalent. The following part analyses the composition of emissions in individual countries, including their development.

Table 1 demonstrates the contribution of emissions from energy to the total CO\(_2\) emissions in individual countries. This area contains emissions from process industries, including construction, and emissions from transportation and other manufacturing sectors. The results indicate that this area of emissions represents the major contributor to the total emissions in the EU28, with the total of 75% with a slightly decreasing trend for the monitored period (for instance, in 2002 the contribution of this group to the total emissions amounted to 77%). If close attention is focused on the development of absolute values within the group, significant differences are evident between the countries. The production of emissions in some states within the group increased considerably, namely in Estonia (by 23.8% to 18.6 mil. tonnes in the monitored period), Bulgaria (by 10%), Luxembourg (by 9%), Poland (by 6%), Lithuania (by 5%), Cyprus (by 4%), as well as Austria (by 1.5%). Contrariwise, the remaining 22 states of the EU28 recorded a decrease in emissions within the energy group, with the most significant value recorded in Denmark (by 37%) or the United Kingdom (by 23%). It is also interesting to examine the emission indicator per capita. The highest ratio is recorded in Luxembourg and Estonia (valid for 2017), where the rate per capita represents 14 tonnes per annum (while the EU28 average is 6.6 tonnes per capita). Conversely, a very low rate per capita is achieved, for instance, by Sweden, Romania, Latvia, and Malta, with the values equalling 3.5 tonnes per capita per annum. There is a significant difference between the lowest and the highest rates per capita, as much as 400%. By and large, there is a 16.2% decrease in emissions from energy in the EU28 in the monitored period, which represents a decrease from 4020 mil. tonnes in 2000 to as few as 3367 mil. tonnes in 2017. The main reason for the decrease is individual countries’ transition to renewable sources of energy, which primarily stems from White Papers—a commitment to produce 12% of energy consumption and 12% of electricity consumption from renewable sources before 2010 (directive 2001/77/ES). Due to an inadequate transition rate, the directive EU 2018/2001 was issued in 2018, which contains a binding target to attain 32% of final energy consumption from renewable sources by 2030. The introduction of biofuels could be another reason for a decrease in the total emissions for transportation, as the agreement to replace 5.75% of petroleum-based fuels by biofuels before 2010 has been in force since 2001, and subsequently increased to 10% of fuels for transportation before 2020 (directive 2009/28/ES). Morales-Lage et al. [29] state that reduced dependency on fossil fuels would contribute not only to an improvement of energy security, but could also limit greenhouse gas emissions, which is one the desired goals for the entire EU.

Within this sector, individual clusters of countries with similar emissions per capita in 2017 have been determined using Statistica. This concerns five clusters in total (Figure 1), with the first containing six countries with the lowest emissions per capita, ranging from 3.6 to 4.2 tonnes, the second containing eight countries with similar values of CO\(_2\) emissions from the energy sector, namely Denmark, Spain, France, Italy, Hungary, Portugal, Slovakia, and the United Kingdom. Their emissions per capita range from 4.7 to 5.9 tonnes/year. The emissions in the countries in cluster 3 range from 6.2 to 7.6 tonnes/capita/year. Cluster 4 contains four countries with emissions per capita ranging from 9 to 9.4 tonnes and cluster 5 contains the countries with the highest rates of CO\(_2\) emissions per capita, namely Estonia and Luxembourg (in this case the values exceed 14 tonnes per capita per annum).
Table 2 illustrates the contribution of emissions from industry to the total emissions in individual states of the EU28. The sector includes emissions from industrial process and product use, mineral industry, chemical industry, metal industry, nonenergy products from fuels and solvent use, electronics industry, product use as substitutes for ozone depleting substances, other product manufacture and use, and other industrial process and product use. The contribution of the total emissions in the category in the examined period is relatively stable at 8%. However, after a more detailed analysis of the absolute values, a decreasing tendency is evident. While in 2000 the total emissions of the EU28 in the category amounted to 455 mil. tonnes, in 2017 these decreased to 377 mil. tonnes (representing a 17% decline). When analysing individual countries, significant disproportions in the emission rate in the category are evident. The highest values are recorded in Slovakia and Austria, where the rate exceeds 20%. The time series analysis indicates an increase in the contribution of the group to the total emissions. Further, some of EU countries recorded a decrease in the contribution of emissions from industry to the total CO\textsubscript{2} emissions, namely Belgium, Bulgaria, Denmark, Germany, Estonia, Ireland, Spain, France, Croatia, Luxembourg, Hungary, The Netherlands, and Romania, contrary to the remaining EU28 countries, where the rate increased. The most considerable increase is recorded in Malta (by 11.8 p.p.) as well as Slovakia (by 4.7 p.p.), Latvia (by 4% p.p.). Growth coefficients and base indices for the development of absolute values have also been computed as part of the time series of emissions from industry. Both increasing and decreasing development tendencies are evident in individual countries. The most significant decline within the base index is evident in The Netherlands and Denmark, where emissions decreased by half in comparison with 2000. Further significant decrease is evident, for instance, in Spain (by 32%), France (by 20%), Germany (by 18%), and other countries. Only smaller countries recorded an increase in the total volume of emissions within industry, such as Czechia (by 5%), Cyprus (by 27%), Latvia (by 312%), Lithuania (by 18%), Malta (by 2116%), Austria (by 17%), Poland (by 13%), Portugal (by 2%), Slovenia (by 4%), and Slovakia (by
When comparing individual countries in terms of CO$_2$ emissions from industry per capita, the results are rather diverse. The EU28 average is 0.7 tonnes per capita per annum. The highest levels are recorded in Austria (2 tonnes per capita), Belgium, and Slovakia (1.8 tonnes per capita). Additional states of the EU28 are above average—Bulgaria, Czechia, Germany, Greece, Cyprus, Lithuania, Luxembourg, Portugal, Finland, Sweden. Contrariwise, very low values are recorded, for example, in Denmark (0.3 tonnes per capita), or the United Kingdom (0.5 tonnes per capita). The difference between the lowest and the highest emission levels per head is significant, equalling 410%.

Figure 2 illustrates individual clusters based on individual countries’ similarities. Cluster 1 contains four countries with the lowest emission levels per capita, namely Estonia, Latvia, Denmark, and the United Kingdom (in this case the emissions range from 0.35 to 0.50 tonnes per capita per annum). The second cluster contains eight countries, predominantly southwestern, such as France, Spain, Italy, The Netherlands, Slovenia, Croatia, and Romania. Their production of emissions per capita ranges from 0.51 to 0.70 tonnes per annum. The third cluster contains seven countries—Bulgaria, Germany, Ireland, Hungary, Poland, Portugal, and Sweden, whose emissions range from 0.71 to 0.90 tonnes per head per year. Cluster 4 contains four countries—Luxembourg, Greece, Lithuania, and Finland. These produce emissions per capita ranging from 1 to 1.30 tonnes per annum. Furthermore, the highest levels are recorded in cluster 5, which contains the following countries: Czechia, Slovakia, Austria, and Belgium. These produce 1.45–2 tonnes of CO$_2$ emissions per capita per annum. It might be concluded that these countries are based primarily on industrial production.

Figure 2. Clusters created based on countries’ similarity in emissions from industry per capita (2017, tonnes).
The following group contributing significantly to the total emissions is one concerning emissions from agriculture (Table 3). This sector includes emissions from livestock, managed agricultural soils, liming, and urea application. A slight decrease of the total emissions is evident in the examined period. While in 2000 these amounted to 461 mil. tonnes, in 2017 they equaled 439 mil. tonnes. The relative contribution to the total emissions in the EU28 in the monitored period increased from 8.7% to 9.8% (an increase of the relative contribution is caused by the fact that emissions from agriculture do not decline as rapidly as the total CO₂ emissions). Within the relative contribution, this is also evident in individual EU28 states, with a decrease in the contribution to the total emissions in 6 countries only, namely Croatia, Cyprus, Luxembourg, Malta, Austria, and Poland (a relative decline up to 1% in all the countries). The remaining countries record an increase in relative contributions, the most notable is evident in Denmark (a 5.5% relative increase in the contribution to the total emissions). Regarding the absolute emission development values from agriculture, only nine states record an increase in the total volume of emissions from agriculture—Bulgaria (by 26% in comparison with 2000), Czechia (by 0.5%), Estonia (by 22%), Latvia (by 23%), Lithuania (by 8%), Luxembourg (by 0.8%), Hungary (by 16%), Poland (by 2.2%), and Romania (by 1.2%). All the remaining EU28 countries record a decrease in the total volume of emissions from agriculture, predominantly the United Kingdom, Spain, Italy, Croatia, Belgium, France, The Netherlands—equally by approximately 10%. Generally, there is a 5% decrease in emissions in the EU28 in the monitored period in comparison with 2000. Should CO₂ emissions from agriculture per head be recomputed, the average value of 0.86 tonnes per capita per annum is obtained. 12 countries in total record a higher value per head than the EU28 average, namely Belgium, Bulgaria, Denmark, Estonia, Ireland (4.1 tonnes per capita), France, Latvia, Lithuania, Luxembourg, The Netherlands, Romania, and Finland. Conversely, for instance, Italy (with 0.5 tonnes per capita), Cyprus, Malta, United Kingdom, and Croatia are well below the average. There is a significant difference between the lowest (Italy) and the highest emission levels (Ireland) per capita, which amounts to 800%. The results indicate the agricultural focus of the countries, since their higher CO₂ emission production suggests a primary focus on animal production.

Figure 3 below illustrates the clusters based on individual countries’ similarities in terms of CO₂ emission production from agriculture. Cluster 1 contains four countries with the lowest emission levels per head, namely Italy, Cyprus, Malta, and Slovakia. These countries’ focus on animal production is insignificant. Their emissions range from 0.14 to 0.58 tonnes per capita per annum. The second cluster contains 14 countries whose emissions per head per year range from 0.61 to 1 tonne. Furthermore, cluster 3 contains six countries whose emissions range from 1.01 to 1.20 tonnes. Cluster 4 is represented by three countries—Denmark, Latvia, and Lithuania. It is evident that the majority of the countries within the EU28 record similar emission levels per year within the agricultural sector. Ireland is an exception, with the emission rate per capita exceeding 4 tonnes per year. In the case of Ireland, a similar result is also presented by Kijewska and Bluszcz [27], with the values of CH₄ (methane) multiple times exceeding the EU average. A focus predominantly on agriculture, the main source of CH₄, is evident here.

The final group that contributes to the total CO₂ emissions concerns waste management. The sector includes emissions from solid waste disposal, biological treatment of solid waste, incineration and open burning of waste, wastewater treatment and discharge, and other methods of disposal. The total emissions in the monitored period demonstrate a significantly decreasing trend. While in 2000 these amounted to 231 mil. tonnes, in 2017 they equalled 139 mil. tonnes (which represents a 40% decrease). Table 4 implies that the contribution of waste to the total emissions is relatively low. In the examined period, a decreasing trend is evident in the relative contribution which equalled 3.1% in 2017. 12 countries in the EU28 record relatively higher contributions to the total CO₂ emissions. The highest values of the relative contribution in 2017 are recorded in Croatia (8.2%), followed by Bulgaria, Portugal, and Malta (approximately 6%). These are followed by Czechia, Greece, Italy, Latvia, Romania with the contribution ranging between 4% and
5%. Conversely, the contribution of emissions from waste disposal is almost negligible in some countries. This is evident, for instance, in Belgium, Germany, Ireland, Estonia, Luxembourg, Netherland, and Austria, where the relative contribution to the total emissions ranges from 0.8% to 1.5%. Further analysis of the development of absolute values implies a decline in emissions in the majority of countries. When comparing values in 2000 and 2017, 21 countries record a significant decrease in emissions from waste disposal, for example, the United Kingdom (by 67%), Sweden (by 61%), The Netherlands (by 70%), Germany (by 64%), or Belgium (by 62%). Merely 7 countries record an increase in emissions from waste disposal, namely Croatia (by 56%), Czechia (by 47%), Cyprus (by 22%), Slovakia (by 18%), Romania (by 11%), and Malta and Spain (identical increase by 8%). When recomputing the emissions from waste management per population, the EU28 average amounts to 0.272 tonnes per capita per annum. A notable disproportion in the results is again evident in individual countries, with the highest emission levels from waste disposal recorded in Cyprus (0.657 tonne per head per year). Bulgaria, Czechia, Greece, Croatia, Italy, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovakia, Finland, and the United Kingdom also recorded above the EU28 average values. There is a significant difference between the lowest and the highest emission levels per person, as much as 500%.

Figure 3. Clusters created based on countries’ similarity in emissions from agriculture per capita (2017, tonnes).

Figure 4 below illustrates clusters arranged based on individual countries’ similarities in terms of CO₂ emissions produced from waste management. Cluster 1 contains 4 countries with the lowest emission levels per person, namely Belgium, Germany, Luxembourg, and Sweden. Their emissions range from 0.10 to 0.15 tonne per capita per annum. The second cluster contains four countries whose emission levels per capita per annum range from 0.16 to 0.20 tonne. Cluster 3 contains 10 countries whose emissions range from 0.21 to 0.33 tonne. Cluster 4 is represented by six countries—Greece, Lithuania, Hungary,
Poland, Portugal, and Finland, whose annual emission levels per person range from 0.34 to 0.45 tonne. The fifth cluster contains four countries whose emission levels per person from waste management are the highest, namely Bulgaria, Czechia, Croatia, and Cyprus, ranging from 0.49 to 0.70 tonne per capita. In this case, significant differences between individual EU28 countries are apparent. The results above imply that stronger emphasis is placed on using landfills instead of incinerators in Western Europe.

![Figure 4. Clusters created based on countries’ similarity in emissions from waste management per capita (2017, tonnes).](image)

The cluster analysis has been conducted for the data from 2000 and 2017, which have been used for comparison. As has been mentioned in the methodology, the division of the countries into clusters was made using agglomerative algorithm and Ward’s method. Please see Figure 5.

The results from 2000 indicate that the total distance of the linkage for all the groups equals 40. Further analysis suggests that 6 basic clusters have been formed that demonstrate similarity in the production of emissions per capita in individual sectors. The first group is composed of the following countries: Lithuania, Latvia, Romania, and Croatia. The second consists of Slovakia, Austria, France, and Spain. The third group contains Malta, Portugal, Sweden, Hungary, and Bulgaria, while the fourth includes Slovenia, Poland, and Italy. The fifth group comprises the United Kingdom, Cyprus, and Greece. The final group consists of Finland, The Netherlands, Estonia, Germany, Denmark, Czechia, and Belgium. In comparison with the remaining countries, Luxembourg’s and Ireland’s structure of emissions in individual sectors is very specific and these countries participate when the distance of the linkage is greater. The results indicate differences in the structure of CO₂ emissions of individual EU28 countries with regard to the focus of a particular economy, predominantly in terms of industry, production sources of energy and agriculture.
be necessary in the future, and agriculture in particular will become a dominant contribution with 1990. Furthermore, the European Commission possesses a strategy to achieve a climate-neutral economy. The aim of this paper has been to monitor the development of individual signatories to reduce CO\(_2\) emissions before 2030 by 40% in comparison with the situation in 1990.

The structure of emissions in individual sectors is very specific and these countries participate not possible to determine the origin and cause of emissions in the examined sectors. Furthermore, there was a 15% decrease in the total CO\(_2\) emissions in the EU28. The contribution of individual elements to the total emissions decreased within the EU28. The contribution of individual signatories to reduce CO\(_2\) emissions before 2030 by 40% in comparison with the situation in 1990.

Perissi et al. [32] draw their attention to the fact that in the monitored period the CO\(_2\) emissions substantially decreased to 4771 (it amounted to 40 in 2000). Individual country clusters also demonstrate minute differences and are generally converging. Figure 6 illustrates individual clusters referring to five groups.

![Cluster analysis for EU28 for 2000.](image1)

Figure 5. Cluster analysis for EU28 for 2000.

After a repeated cluster analysis for data from 2017, greater convergence of individual clusters can be observed. The total distance between the linkage in this case decreases to 28 (it amounted to 40 in 2000). Individual country clusters also demonstrate minute differences and are generally converging. Figure 6 illustrates individual clusters referring to five groups in total. The first comprises Lithuania, Malta, Latvia, Sweden, Romania, and Croatia. The second larger group consists of Portugal, Hungary, France, the United Kingdom, Italy, Spain, and Denmark. The following group includes Poland, The Netherlands, Germany, and Czechia, and implies similarity in terms of the countries’ industrial burden. The penultimate cluster is comprised of Slovakia, Austria, Slovenia, Greece, Bulgaria, Cyprus, Finland, and Belgium. Luxembourg and Estonia also demonstrate similar contributions of emissions from individual groups, although simultaneously they engage in the system last with the total distance of the linkage equalling 20.

![Cluster analysis for EU28 for 2017.](image2)

Figure 6. Cluster analysis for EU28 for 2017.
In order to investigate the differences in greenhouse gas emissions in the assessed countries, cluster analysis has been employed by several researchers [25,27,28,30]. Ward’s method has been used for instance by Bolea, Duarte and Sánchez-Chóliz [30]. The results of their studies imply a distinction in the production of CO$_2$ emissions of individual countries mainly with regard to the individual structure of their national economy. This indicates international inequality regarding environmental pressure and transfer of environmental damage.

De Araújo, Jackson, Neto et al. [31] emphasise the fact that although the emissions of the new EU countries (accession after 2004) generally decreased, the changes are not sufficient. The reason could be an increase in emissions caused by the development of international trade. CO$_2$ emissions contained in export of final products are particularly noteworthy.

Perissi et al. [32] draw their attention to the fact that substantial decarbonisation will be necessary in the future, and agriculture in particular will become a dominant contributor to the total CO$_2$ emissions owing to the use of biomass both for food and biofuels.

4. Conclusions

The obligations deriving from the Paris Agreement about climate imply a commitment of individual signatories to reduce CO$_2$ emissions before 2030 by 40% in comparison with 1990. Furthermore, the European Commission possesses a strategy to achieve a climate-neutral economy. The aim of this paper has been to monitor the development of individual EU28 countries in the period between 2000 and 2017 in terms of the production of CO$_2$ emission equivalents.

Using aggregated data in this study presents certain limitation as based on these it is not possible to determine the origin and cause of emissions in the examined sectors. Future research will focus on a more detailed analysis of the origin of CO$_2$ emissions with the focus on agriculture, which is a significant producer of greenhouse gases. An additional research option could be to compare the current results with the values for 2020 and 2021 when due to the covid-19 outbreak there has been a reduction in emissions produced especially by industrial and transport entities. The added value of the current study is in that it analyses the sectors which contribute to the total CO$_2$ emissions in the EU28 countries per capita and provides a map which illustrates the division of the countries into clusters. The cluster analysis then enables detection of the differences between individual countries in the emission structure, which occurred in the period between 2000 and 2017.

The results indicate that in the monitored period the CO$_2$ emissions substantially decreased within the EU28. The contribution of individual elements to the total emissions implies a significant difference in the development of individual countries, which probably derives from different laws that regulate CO$_2$ emissions.

Additionally, there was a 15% decrease in the total CO$_2$ emissions in the EU28 countries despite the continual population growth. Kijewska and Bluszcz [27] also record similar results for the period 1990–2012 when there was a 19% decrease in emissions within the EU. A transfer to renewable sources of energy, such as solar, wind, and biogas stations, as well as an effort to decrease emissions produced by automobile transport, are also important aspects for reducing emissions.

After a detailed examination of the individual countries, it could be concluded that in some there is an increase of the total value of produced emissions between 2000 and 2017, namely in Bulgaria, Estonia, Cyprus, Latvia, Lithuania, Luxembourg, Austria, and Poland.

The results suggest that the energy category records the largest contribution to the total emissions, equalling 75% of the EU28. This level is exceeded by seven countries in total, which could indicate heavy dependence on fossil fuels. In some countries, the contribution exceeds 80% (for example, in Estonia, Poland, and Germany).

The contribution of emissions from industry in the EU28 oscillates at approximately 8.5%. However, based on individual countries’ results, it could be concluded that 16 states exceed the average. The highest levels in this regard are attained by Slovakia and Austria,
with the contribution exceeding 20%. The values per capita are interesting and indicate countries focused on industry, namely Austria, Slovakia, Belgium, and Czechia.

In terms of the total emission volume, agriculture demonstrates a declining trend, although in a relative term its contribution to the total emissions is increasing. During the monitored period, the relative contribution increased to 10%, therefore it succeeds the energy sector as the second most significant contributor to the total emissions. The results imply that some countries are heavily focused on agricultural production, since the contribution of emissions from agriculture amounts to as much as 30%, mainly Ireland, Denmark, Latvia, Lithuania, and Romania.

The final examined sector is waste disposal. The results in this section are rather interesting, since there is an up to 40% decrease of the total emissions in the EU28 which, in absolute terms, amounts to 93 mil. tonnes of CO$_2$. This decline is produced predominantly by the Western European countries, where it is most notable (Germany, The Netherlands, France, and Poland). Lower emission levels in Western Europe are a result of considerably more significant contribution of recycling and composting. For instance, in Belgium or The Netherlands the contribution amounts to almost 60%, while in Czechia or Croatia the value of the indicator is 30%. It could generally be concluded that landfills or waste incineration prevail in Eastern and Southern European countries. However, some recorded a substantial increase in emissions in the monitored period. In terms of absolute values, the most significant increase can be detected in Czechia (by 1.8 mil. tonnes of CO$_2$), followed by Spain, Croatia, Cyprus, Malta, Romania, and Slovakia. A comparison of CO$_2$ emissions from waste per capita is also interesting. In this regard, the EU28 average oscillates at 0.272 tonnes/capita. The worst results are reported by Cyprus (0.65 tonnes/capita), followed by Bulgaria and Czechia (0.534 tonnes/capita), whereas in the Western European countries, for example in Belgium or Germany, the indicator amounts to mere 0.13 tonnes/capita).

When examining the total CO$_2$ emissions in individual EU28 countries per capita, it can be stated that the highest levels are recorded in Luxemburg (20.2 tonnes/capita). However, the average for the EU28 amounts to 8.8 tonnes per capita. 12 of the analysed countries exceed this average, namely Belgium (10.5 tonnes/capita), Czechia (12.3 tonnes/capita), Germany (11.3 tonnes/capita), Estonia (16 tonnes/capita), Ireland (13.3 tonnes/capita), Greece (9.2 tonnes/capita), Cyprus (11.6 tonnes/capita), The Netherlands (12 tonnes/capita), Austria (9.6 tonnes/capita), Poland (11 tonnes/capita), and Finland (10.4 tonnes/capita). Conversely, the best results are achieved by Sweden (5.5 tonnes/capita), followed by France (7.2 tonnes/capita), Italy (7.2 tonnes/capita), and Spain (7.7 tonnes/capita).

In terms of the effort to fulfil the EU commitment to reduce the total emissions, positive tendencies in the development are evident from the results. Simultaneously, vast heterogeneity of the EU28 states has been detected when evaluating the structure and the contribution of the emission-producing sectors. Regarding the economic differences, it is necessary that individual countries impose specific measures with a clearly defined objective to minimize their CO$_2$ emissions.

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