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## A comparative analysis of the European Union member states in terms of public spending on environmental protection in 2004-2017

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**Abstract.** The main purpose of the paper is to present the results of the comparative analysis of the member states of the European Union in terms of expenditure on environmental protection made by the public sector. An additional purpose of the paper is to verify whether there is convergence in public spending on environmental protection of the member states of the European Union. In the study, the convergence models and cluster analysis were used. The research results indicate, among others, that there was convergence in total public spending on environmental protection in the member states of the European Union in 2004-2017, and that the structure of the member states in terms of amounts of public spending on various aspects of environmental protection in 2004-2010 differed from the structure of the member states determined for the years 2011-2017.

**Keywords.** convergence; environmental protection; EU member states; public spending

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### 1. Introduction

The origins of the European Union's environmental policy can be traced back to the meeting of the European Council in Paris in 1972. At this meeting, the heads of state or government pointed to the need to develop the Community environmental policy. Since 1973, the European Commission has been announcing multi-annual Environmental Action Programmes (EAP). They define, among other things, future objectives of the EU environmental policy (European Parliament, *Environment Policy: General Principles and Basic Framework*).

In 2013, the EU Council and Parliament adopted the seventh EAP for the period up to 2020 entitled *Living well, within the limits of our planet*. The seventh EAP lists nine priority objectives and what the EU needs to do to achieve them by 2020. They are (European Commission, *Living well, within the limits of our planet. 7th EAP – The new general Union Environment Action Programme to 2020*): '1) to protect, conserve and enhance the Union's natural capital; 2) to turn the Union into a resource-efficient, green, and competitive low-carbon economy; 3) to safeguard the Union's citizens from environment-related pressures and risks to health and wellbeing; 4) to maximise the benefits of the Union's environment legislation by improving implementation; 5) to increase knowledge about the environment and widen the evidence base for policy; 6) to secure investment for environment and climate policy and account for the environmental costs of any

*societal activities; 7) to better integrate environmental concerns into other policy areas and ensure coherence when creating new policy; 8) to make the Union's cities more sustainable; 9) to help the Union address international environmental and climate challenges more effectively'.*

The implementation of the priority objectives of the EAP is supported, among others, by a public expenditure of the European Union Member States. The information on public spending on environmental protection in the European Union member states is available, for example, on Eurostat, which publishes data according to the classification of the public sector spending as per the COFOG (the Classification of the Functions of the Government) functions, in which public sector means the general government.

The COFOG encompasses 10 types of functions performed by public authorities (i.e. 10 divisions broken down into groups and classes): GF01 – General public services, GF02 – Defence, GF03 – Public order and safety, GF04 – Economic affairs, GF05 – Environmental protection, GF06 – Housing and community amenities, GF07 – Health, GF08 – Recreation, culture and religion, GF09 – Education, GF10 – Social protection.

Financial data grouped according to the COFOG may be the basis for comparative analyses of the general government expenditure in various countries. Unfortunately, problems arise in the case of attempts to classify certain types of expenditure at the levels of the classification lower than the division. As a result, data concerning more detailed levels of the COFOG are not always available to the full extent for all member states of the European Union.

In the literature, there are publications presenting studies on the impact of public spending on the level of the economic development of countries (Pitlik and Schratzenstaller, 2011; Ryu, 2015). They demonstrate the existence of a positive correlation between the GDP and productive expenditure, and a negative correlation between the GDP and unproductive expenditure.

Pitlik and Schratzenstaller (2011), on the basis of the findings of macroeconomic studies on the impact of fiscal policies on the level of economic development, divided public spending according to the COFOG into productive and unproductive expenditure. Public expenditure on environmental protection was classified as productive expenditure, but with a comment that its impact on the level of economic development was being challenged.

Countries have also been compared in terms of public expenditure by 10 divisions according to the COFOG using cluster analysis methods for this purpose (Ferreiro et al., 2010, 2013), and the occurrence of convergence in total public spending has been studied (Apergis et al., 2013; Ferreiro et al., 2013).

The concepts of convergence as a phenomenon occurring in economic systems are quite varied. Among the processes that favour the convergence of economic systems, Giertz and Mehta (1996) list a state policy, understood as the use by the state of various solutions in the institutional, tax, infrastructure and social spheres.

Ferreiro et al. (2013) presented the findings of the study on the occurrence of convergence in total public spending (as a percentage of GDP) and in public spending by divisions of the Economic Classification (as a percentage of total public expenditure) and the COFOG (as a

percentage of total public expenditure) in the years 1990-1998 and 1999-2007. The study was carried out using the box plot. First of all, the variability of the distributions of total public expenditure and public expenditure by divisions in the two analysed periods was compared. In addition, the cluster analysis based on public expenditure by divisions of the Economic Classification and the COFOG separately was carried out. The PCA (Principal Component Analysis) was performed in the analysis. In the COFOG, the data matrix is formed by 20 countries and 11 variables: the shares of the 10 items (as a percentage of total spending) and the size of public expenditure (as a percentage of GDP). The EU member states were clustered based on the five factors indicated by the PCA with the application of Ward's criterion. Seven clusters were created for the 1990-1998 data. For the data from the period 1999-2007, there was a smaller number of clusters than in the previous period, i.e. five clusters. Based on the study findings, the authors concluded that convergence had occurred in public spending in the years 1990-2007.

On the other hand, Apergis et al. (2013) studied the occurrence of convergence in public spending by 10 divisions of the COFOG based on data from 17 EU member states from the period 1990-2012. The methodology proposed by Phillips and Sul (2007) was applied. On the basis of the estimated regression model, the absence of convergence in total public expenditure and in public spending by divisions of the COFOG was confirmed. Next, the dip-test (Hartigan and Hartigan, 1985) was applied to verify the null hypothesis that the distribution was unimodal. At the significance level of 0.10, the test outcomes resulted in the rejection of the null hypothesis for the majority of public spending as per the COFOG functions; spending on environment protection was the only exception. Hence, when applying two approaches to the convergence study, conflicting results were obtained for public expenditure on environmental protection.

Among publications on government spending on environmental protection, there are deliberations on selected aspects of the environmental protection. Public social expenditure is a popular area of study (e.g. (Halaskova, 2018; Leitner and Stehrer, 2016; Szarowska, 2011)). Halaskova (2018) clustered countries due to their public social expenditure. Convergence in the case of public social expenditure was also studied (De Simone et al., 2010). A much smaller number of publications refer to public expenditure on environmental protection only (Russu, 2017), also in break-down by groups (Ercolano and Romano, 2018). Russu (2017) analyzed public expenditure on environmental protection made in Romania as compared to other European Union member states in 1990, 1995, 2000, 2005, 2010 and 2012.

Ercolano and Romano (2018) studied the occurrence of convergence in public spending on environmental protection in terms of its total amount and for six aspects of environmental protection distinguished in the COFOG, expressed as a percentage of the GDP. The analysis was based on the data concerning 21 EU member states from 2002-2010. The occurrence of sigma-convergence was studied based on the box plot and the measures of the variability of distributions of total spending in the years 2002-2010, and of spending by six groups in 2002, 2006 and 2010. On the basis of the results obtained, the conclusion was drawn about the

absence of convergence in total public spending on environmental protection. In turn, the results obtained for the six aspects of environmental protection varied. In the case of expenditure on 'Protection of biodiversity and landscape' and 'R&D Environmental protection', convergence was confirmed; in the case of spending on 'Waste water management' and 'Environmental protection n.e.c.', divergence was confirmed; and in the case of 'Waste management' and 'Pollution abatement', the findings of the analysis were not sufficiently conclusive to confirm either convergence or divergence. In addition, a cluster analysis was performed using Ward's method and the main factors indicated by the PCA for object-periods representing 21 EU member states in 2002, 2006 and 2010. The states were partitioned into five clusters. The analysis of the assignment of three objects representing individual member states in 2002, 2006 and 2010 became the basis for the conclusion about the diversity of EU member states in terms of trends existing in public spending on environmental protection in 2002, 2006 and 2010.

This paper is part of the research trend represented by Apergis et al. (2013) at the level of total public expenditure on environmental protection, and Ercolano and Romano (2018) at the level of the six groups of public expenditure on environmental protection as per the COFOG. Modifications of the research approach applied can also be found in the publications of Halaskova (2018) and De Simone et al. (2010).

The main purpose of the paper is to present the results of the comparative analysis of 27 member states of the European Union in terms of expenditure on environmental protection made by the public sector. An additional purpose of the paper is to verify whether there is convergence in public spending on environmental protection of the member states of the European Union. The analysis covers the years 2004-2017, using the data from Eurostat.

The following research questions have been formulated:

1. Was there any convergence in total public spending on environmental protection in the member states of the European Union in 2004-2017?
2. Was the structure of countries in terms of amounts of public spending on various aspects of environmental protection the same in 2004-2010 and 2011-2017?
3. Was there any relationship between the structure of countries in terms of amounts of public spending on various aspects of environmental protection in 2004-2010 and 2011-2017 and the length of the membership of these countries in the European Union?
4. Was there any relationship between the structure of countries in terms of amounts of public spending on various aspects of environmental protection in 2004-2010 and 2011-2017 and the level of economic development of these countries?

To the author's best knowledge, to date, there have been no comparative analyses of the 27 member states of the European Union in terms of government expenditure on various aspects of environmental protection according to the COFOG, or studies on the occurrence of convergence in public spending on environmental protection in the 27 EU member states in 2004-2017. In this context, the presented results of the cluster analysis conducted on the set of

27 countries from the European Union using the data on public expenditure on various aspects of environmental protection in 2004-2010 and 2011-2017, and a study on the occurrence of beta- and sigma-convergence in total public spending on environmental protection in the analyzed countries in 2004-2017, are new in the literature.

The paper structure is as follows: Section 1 presents the objectives of the paper and the research questions; Section 2 presents the discussion of the research procedure; Section 3 presents the results of the empirical study with a discussion, and Section 4 is a summary of the considerations.

## 2. Data and methods

The comparative analysis of the European Union member states was carried out in accordance with the following research procedure:

1. Downloading data from Eurostat
2. Verifying the data set in terms of its validity and completeness
3. Describing selected empirical distribution characteristics
4. Studying the occurrence of convergence
5. Creating two data sets for the years 2004-2010 and 2011-2017
6. Normalising variables
7. Determining the optimum number of clusters
8. Countries clustering
9. Cluster validation
10. Presenting the description of the clusters
11. An attempt at cluster profiling

The comparative analysis of the European Union member states in terms of government expenditure on environmental protection was based on annual data downloaded from Eurostat (<https://ec.europa.eu/eurostat>). The study subjects comprised the member states of the European Union (28 states at the outset). The author downloaded the data from Eurostat for 'General government expenditure by function' (GF05) broken down into:

- GF0501 – Waste management (million euros)
- GF0502 – Waste water management (million euros)
- GF0503 – Pollution abatement (million euros)
- GF0504 – Protection of biodiversity and landscape (million euros)
- GF0505 – R&D Environmental protection (million euros)
- GF0506 – Environmental protection n.e.c. (million euros)

In addition, the following data were also downloaded: 'Population (Total number)' and 'GDP (Current prices, million euros)'. Next, per capita GDP, per capita GF05 and GF0501, ..., GF0506 as a percentage of GDP were calculated.

The study period covered the years 2004-2017. Until 2004, the European Union comprised

15 member states (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, the United Kingdom). In 2004, 10 countries joined the EU (Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia). Bulgaria and Romania joined the EU in 2007, and Croatia in 2013. Due to the absence of many data for Bulgaria in the database, this state was excluded from the analysis.

In the database downloaded from Eurostat, there were *negative values of public expenditure*. Based on the clarifications presented in the publication (Eurostat and European Commission, 2011, p. 40): '(...) *The problem might be a recording error, or more likely it might be the result of the compilation process, often in connection with the functional classification of final consumption expenditure P.3 and the distribution between the individual and collective components. Even in this latter case, however, the negative values should be eliminated because negative values of public expenditure have no economic significance (...)*', negative values were replaced with zeros.

The box plot was applied to present selected distribution characteristics of empirical data concerning government expenditure on environmental protection. This graph is used to visualize some distribution characteristics of a variable. In this study, the box plot based on positional measures was used.

In the case of classical convergence, beta-convergence and sigma-convergence are distinguished. Beta-convergence occurs when countries with lower expenditure per capita increase it faster than the countries with higher expenditure per capita. In the case of beta-convergence, absolute convergence and conditional convergence are also distinguished. The former type of convergence is based on the assumption that amounts of expenditure per capita in individual countries converge to the same level called 'the steady state'. Conditional convergence is a situation in which each country has its individual level of the steady state. Sigma-convergence occurs when the variability of the amounts of expenditure per capita in a particular group of countries measured with, for example, a standard deviation, decreases over time.

In the study of the occurrence of convergence, the occurrence of absolute beta-convergence and of sigma-convergence was verified:

1. Absolute beta-convergence (Barro and Sala-i-Martin, 1992):

$$\frac{1}{T} \ln \left( \frac{y_{iT}}{y_{i0}} \right) = \alpha_0 + \alpha_1 \ln(y_{i0}) + \varepsilon_i, \quad (1)$$

where:

$y_{i0}, y_{iT}$  – the amount of public spending on environmental protection in the  $i$ -th country per inhabitant in the initial and final periods,

$T$  – the length of the analyzed period.

If the regression coefficient is statistically significant, and the assessment of this coefficient is a negative value, there is absolute beta-convergence in public spending on environmental protection in the EU member states.

The rate of convergence can be calculated using a regression coefficient assessment according to the following formula:

$$\beta = -\frac{1}{T} \ln(1 + a_1 T). \quad (2)$$

The  $\beta$  coefficient shows the percent of the distance to the steady state that an economy covers in one period.

## 2. Sigma-convergence (Friedman, 1992; Quah, 1993):

$$\sigma_t = \gamma_0 + \gamma_1 t + \varepsilon_t, \quad (3)$$

where:

$\sigma_t$  – standard deviation of logarithmic amounts of public spending on environmental protection in the member states per inhabitant,

$t$  – time.

If the slope parameter in the linear trend is statistically significant, and the assessment of this parameter is negative, then there is sigma-convergence in government spending on environmental protection in the EU member states.

To eliminate the impact of short-term changes on the results of the comparative analysis of member states in terms of public spending on environmental protection, the annual data from the period of seven years were averaged. As a result, two periods were obtained covering the years 2004-2010 and 2011-2017. Each period was represented by average values calculated on the basis of annual data for a particular period.

The Wilcoxon matched-pairs test (Wilcoxon, 1945) was used to check if public spending on environmental protection for the two periods differ.

Variables were normalised with the application of the unitarisation method with fixed parameters over time:

$$y_{ijt} = \frac{x_{ijt} - \min_{i,t}\{x_{ijt}\}}{\max_{i,t}\{x_{ijt}\} - \min_{i,t}\{x_{ijt}\}}, \quad (4)$$

where:

$x_{ijt}$  – the value of  $X_j$  variable for the  $i$ -th object in period  $t$ ,

$y_{ijt}$  – the normalised value of  $X_j$  variable for the  $i$ -th object in period  $t$ .

The member states were clustered using Ward's method. Ward's method minimises the total

within-cluster variance. At each step, the pair of clusters with minimum cluster distance are merged. To implement this method, at each step one must find the pair of clusters that leads to a minimum increase in total within-cluster variance after merging. The calculations were made using the 'NbClust' function from the 'NbClust' package in R environment with 'ward.D2' option, which implements Ward's (1963) clustering criterion (Murtagh and Legendre 2014).

As a result of the application of hierarchical Ward's method, a set of partitions was obtained for each period, from a partition containing 27 single-element clusters to a partition containing only one 27-element cluster. Due to the sample size (27 member states), the assumed maximum number of clusters was 6. For partitions containing from 2 to 6 clusters, the values of selected cluster validity measures were calculated: Krzanowski-Lai (K-L) index (Krzanowski and Lai, 1988), Calinski-Harabasz (C-H) index (Calinski and Harabasz, 1974), Davies-Bouldin (D-B) index (Davies and Bouldin, 1979). On the basis of the values of the indices above, the optimum number of clusters was determined.

For each of the two partitions (for the periods: 2004-2010 and 2011-2017), the validity of country assignment to the clusters was assessed using the Silhouette (S) index (Rousseeuw, 1987). Finally, the two partitions were compared with the adjusted Rand index (Rand, 1971; Hubert and Arabie, 1985; Gates and Ahn, 2017).

The variables that were used in the clustering of objects are the basis for the description of clusters. Therefore, the average values calculated for public expenditure made by member states from a given cluster on particular aspects of environmental protection were used to describe the clusters.

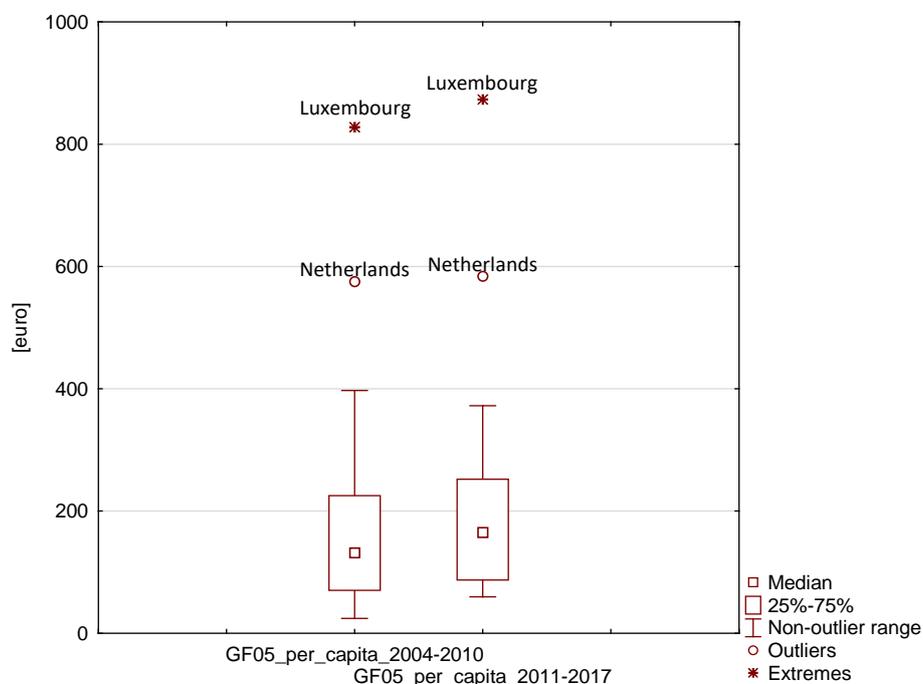
In the end, an attempt at cluster profiling was made. Profiling is carried out on the basis of the variables that were not used in the clustering of objects. Its purpose is to indicate such attributes of objects that can explain the discovered structure of clusters. In this study, two qualitative attributes were taken into consideration, i.e.:

1. the period of a state's membership in the European Union:
  - 'old' – a state that joined the EU before 2004,
  - 'new' – a state that joined the EU in 2004 or later;
2. the level of economic development:
  - 'GDP\_1' – a state with per capita GDP below the first quartile calculated for the EU member states in a particular period,
  - 'GDP\_2' – a state with per capita GDP between the first quartile and the median,
  - 'GDP\_3' – a state with per capita GDP between the median and the third quartile,
  - 'GDP\_4' – a state with per capita GDP above the third quartile.

The selection of attributes for cluster profiling was related to an attempt at investigating whether the diversity of the European Union member states in terms of public spending on various aspects of environmental protection was related to the 'old-15' or 'new-13' status of the member states or to varying levels of their economic development.

### 3. Findings and discussion

Selected empirical distribution characteristics of the analysed variables were presented using the box plot. Figure 1 presents the distribution characteristics of per capita public expenditure on environmental protection in the European Union member states in 2004-2010 and 2011-2017.

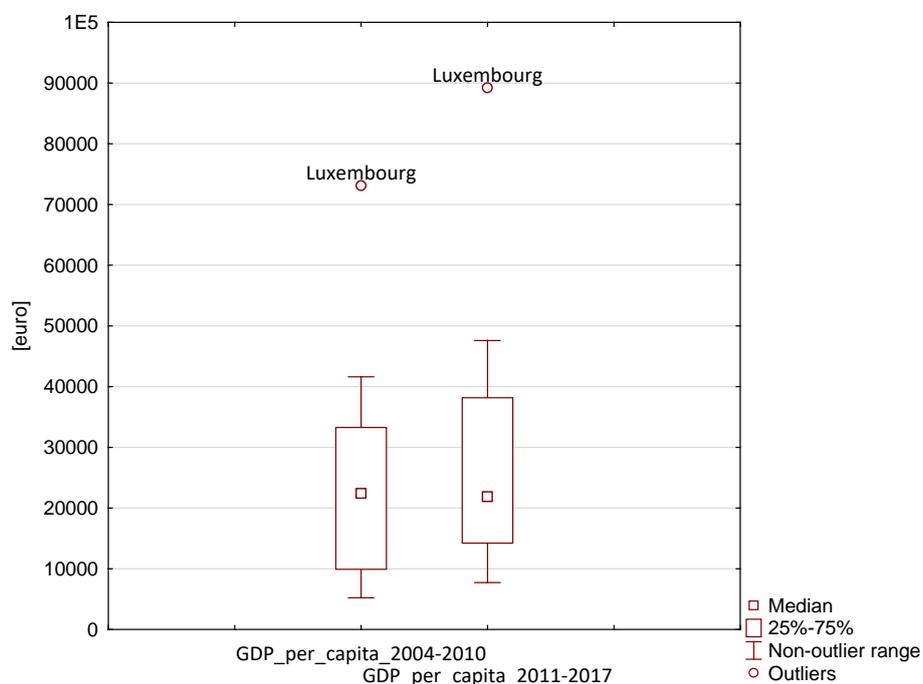


**Figure 1.** Empirical distribution characteristics of per capita public expenditure on environmental protection in the EU member states in 2004-2010 and 2011-2017. Source: author's own study carried out using the 'STATISTICA' program.

When comparing the distribution characteristics, it can be concluded that the average value of per capita public expenditure on environmental protection measured with the median increased in 2011-2017 as compared to the period 2004-2010; the values of the first and third quartiles also increased. In both periods, per capita expenditure made in Luxembourg and the Netherlands was substantially higher than the expenditure made in other European Union member states. It should be noted that the range containing non-outlier values in the period 2011-2017 was shorter as compared to the period 2004-2010. At the significance level of 0.05, the Wilcoxon matched-pairs test showed a statistically significant difference between public spending on environmental protection per capita in the European Union member states in the two periods under consideration ( $p$ -value equals 0.0095).

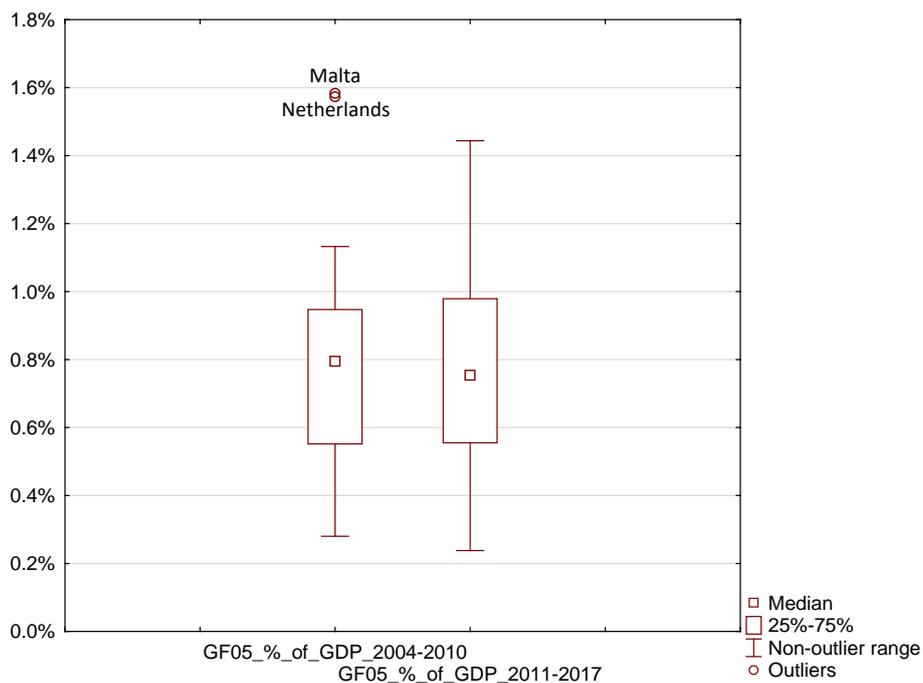
This may indicate the occurrence of convergence in public spending on environmental protection in the European Union member states. It seems that the observed regularity may be associated with the progressing economic development as measured with per capita GDP of the member states of the European Union (Figure 2). In the case of per capita GDP in 2004-2010 and 2011-2017, an increase in the value of the first and third quartiles with the constant value of the interquartile range and a slight decrease in the value of the median can be

observed. At the significance level of 0.05, the Wilcoxon matched-pairs test showed a statistically significant difference between the GDP per capita in the European Union member states in the two periods under consideration ( $p$ -value is less than 0.0001).



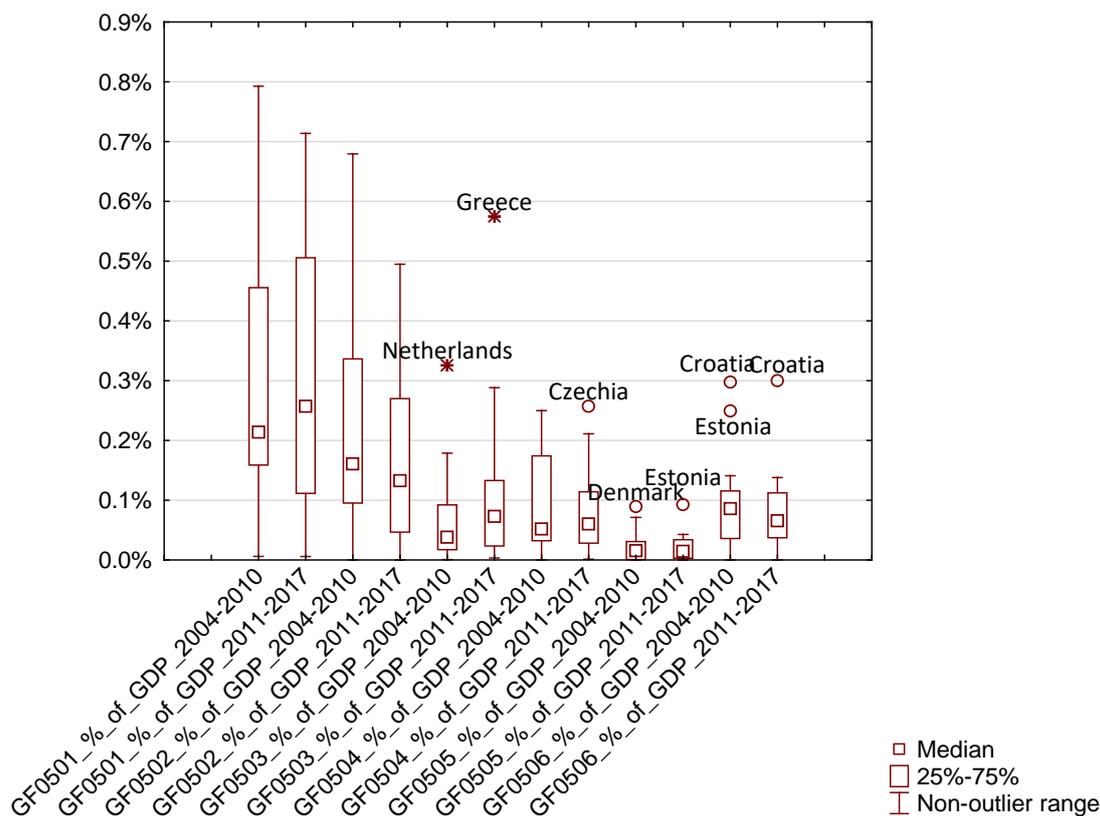
**Figure 2.** Empirical distribution characteristics of per capita GDP in the EU member states in 2004-2010 and 2011-2017. Source: author's own study carried out using the 'STATISTICA' program.

Next, the author verified whether an increase in the average amount of per capita public expenditure on environmental protection was accompanied by an increase in the amount of this type of expenditure in relation to the GDP. Figure 3 presents the empirical distribution characteristics of the amounts of expenditure as a percentage of the GDP. When comparing the graphs obtained for the analyzed periods, it can be observed that the average amount of expenditure measured with the median decreased in 2011-2017 as compared to 2004-2010. In addition, the length of the range containing non-outlier values increased in the period 2011-2017 as compared to 2004-2010. Therefore, a situation opposite to that occurring for per capita expenditure is observed. But at the significance level of 0.05, the Wilcoxon matched-pairs test did not show a statistically significant difference between public spending on environmental protection as a percentage of the GDP in the European Union member states in the two periods under consideration ( $p$ -value equals 0.2029).



**Figure 3.** Empirical distribution characteristics of public expenditure on environmental protection (as a percentage of the GDP) in the EU member states in 2004-2010 and 2011-2017. Source: author’s own study carried out using the ‘STATISTICA’ program.

When analysing medians of public spending on various aspects of environmental protection (Figure 4), it can be observed that the median increased in the period 2011-2017 as compared to the period 2004-2010 in the case of the expenditure on the following aspects: ‘Waste management’, ‘Pollution abatement’ and ‘Protection of biodiversity and landscape’. The reduction of the non-outlier range is observed only for expenditure on the aspects: ‘Waste management’, ‘Waste water management’, ‘Protection of biodiversity and landscape’ and ‘R&D Environmental protection’. However, at the significance level of 0.05, the Wilcoxon matched-pairs test showed a statistically significant difference between public spending on environmental protection (as a percentage of the GDP) in the European Union member states in the two periods under consideration only on ‘Waste water management’ and ‘Environmental protection n.e.c.’ ( $p$ -value equals 0.0031 and 0.0299 respectively).



**Figure 4.** Empirical distribution characteristics of public expenditure on various aspects of environmental protection (as a percentage of the GDP) in the EU member states in 2004-2010 and 2011-2017. Source: author's own study carried out using the 'STATISTICA' program.

The study of the occurrence of convergence in public spending on environmental protection in the member states of the European Union began with the estimation of the model (1):

$$\frac{1}{13} \ln \left( \frac{y_{i,13}}{y_{i,0}} \right) = 0.1726 - 0.0305 \ln(y_{i,0}) \quad (R^2 = 0.5719) \quad (13)$$

At the significance level of 0.05, the parameters of the model (13) are statistically significant ( $p$ -value is less than 0.01). Since the assessment of the regression coefficient ( $\alpha_1$ ) is a negative value, it can be concluded that there is absolute beta-convergence in public spending on environmental protection in the EU member states. This conclusion means that the member states with a lower expenditure of this type per capita increase their spending on environmental protection faster than those member states with higher per capita public expenditure on environmental protection.

In addition, the coefficient of the rate of convergence (2) was calculated:  $\beta = 0.0388$ . The  $\beta$  coefficient indicates that the EU economy covers in one year ca. 3.9% of the distance to the steady state.

Next, the occurrence of sigma-convergence was verified. To this end, the linear trend function (3) was estimated:

$$\sigma_t = 0.9144 - 0.0190t \quad (R^2 = 0.5576) \quad (14)$$

At the significance level of 0.05, the parameters of the model (14) are statistically significant ( $p$ -value is less than 0.01). Since the assessment of the slope value ( $\gamma_1$ ) in the linear trend is negative, it can be concluded that there is sigma-convergence in government spending on environmental protection in the EU member states.

The measures applied to assess the cluster validity are based on various criteria. Thus, in research practice, the indications regarding the optimum number of clusters may vary depending on the adopted measure (Sokolowski et al., 2019). In this study, three popular measures were used to assess the cluster validity, i.e. the Krzanowski-Lai index, Calinski-Harabasz index and Davies-Bouldin index. Table 1 presents three indications for each of the analyzed measures in the order corresponding to the descending cluster validity level. Bold font was used to highlight the number of clusters selected for subsequent analysis.

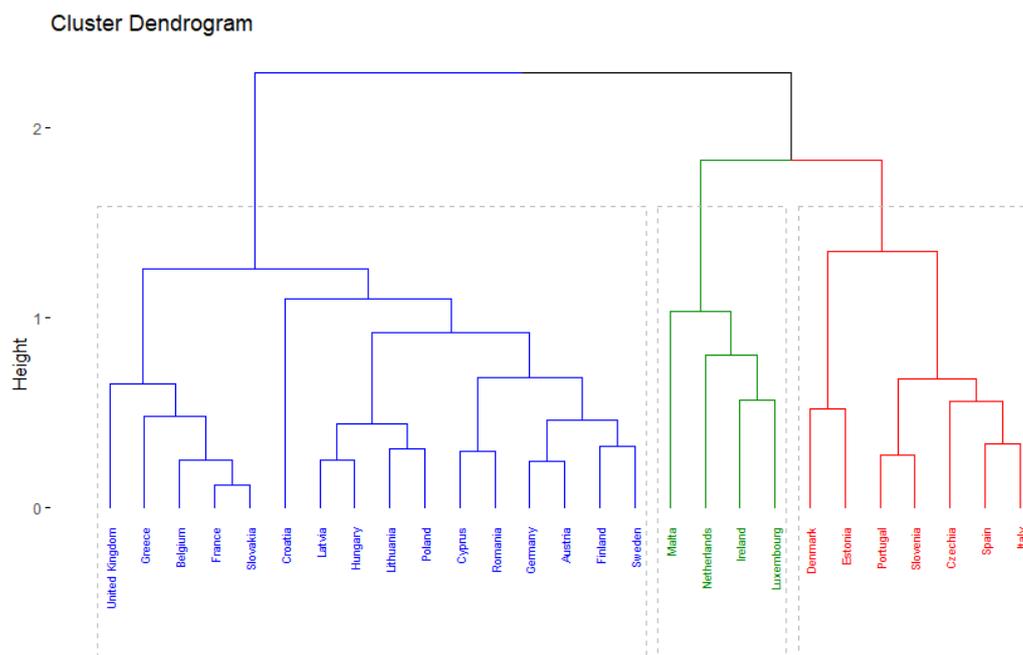
**Table 1.** Cluster validity measures.

Measure	2004-2010		2011-2017	
	Optimum number of clusters	Index value	Optimum number of clusters	Index value
K-L	<b>3</b>	1.7001	<b>6</b>	1.2323
	5	1.1307	3	1.0053
	6	0.9670	4	0.9077
C-H	<b>3</b>	9.5808	<b>6</b>	6.4562
	2	9.3014	5	6.0149
	6	8.9929	3	5.9522
D-B	6	1.0265	<b>6</b>	1.0419
	4	1.0678	5	1.2569
	5	1.1881	4	1.3497

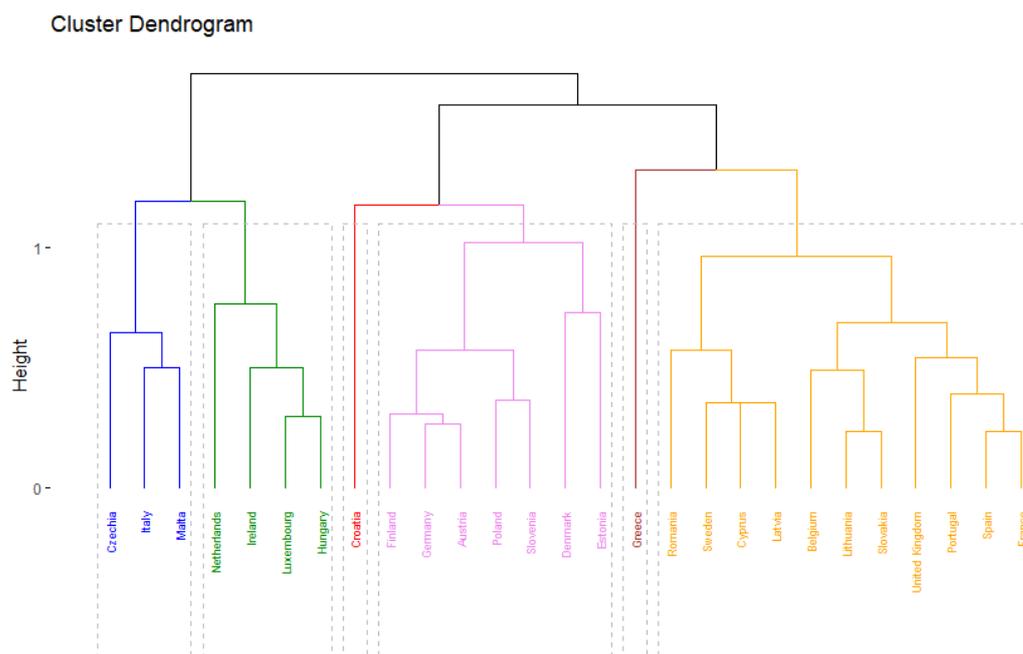
Source: the author's calculations made using the 'NbClust' package in R environment (Charrad et al., 2014).

On the basis of the values of the cluster validity measures from Table 1, the author decided that for the years 2004-2010, the member states of the European Union would be partitioned into three clusters, and for the years 2011-2017 into six clusters. The higher number of clusters for 2011-2017 than for 2004-2010 can be interpreted as information about the greater diversity of the European Union member states in 2011-2017 than in 2004-2010 in terms of the funds allocated to various aspects of environmental protection expressed as a percentage of a particular member state's GDP.

Figures 5 and 6 present dendrograms obtained using Ward's method with squared Euclidean distance for the years 2004-2010 and 2011-2017. Colours are used to mark clusters of member states similar in a given period in terms of funds allocated to various aspects of environmental protection expressed as a percentage of a particular member state's GDP.



**Figure 5.** Dendrogram for the years 2004-2010. Source: author's own study carried out using the 'factoextra' package in R environment (Kassambara and Mundt, 2017).



**Figure 6.** Dendrogram for the years 2011-2017. Source: author's own study carried out using the 'factoextra' package in R environment (Kassambara and Mundt, 2017).

Table 2 presents the compositions of the clusters obtained as a result of the partitioning of the member states of the European Union on the basis of the data from 2004-2010 and 2011-2017. In addition, the table lists the Silhouette index values calculated to assess the validity of the assignment of individual member states to the created clusters.

**Table 2.** Compositions of the clusters obtained as a result of the partitioning of the European Union member states on the basis of data from 2004-2010 and 2011-2017.

2004-2010					2011-2017					
Class	Country	Index S(j)	UE	GDP	Class	Country	Index S(j)	UE	GDP	
C_1	Romania	0.448	new	GDP_1	C_1	Latvia	0.386	new	GDP_1	
	Cyprus	0.426	new	GDP_3		Slovakia	0.375	new	GDP_2	
	Greece	0.419	old	GDP_2		United Kingdom	0.318	old	GDP_3	
	Hungary	0.419	new	GDP_1		Belgium	0.310	old	GDP_3	
	Sweden	0.407	old	GDP_4		Lithuania	0.280	new	GDP_1	
	Slovakia	0.396	new	GDP_2		Cyprus	0.230	new	GDP_3	
	Belgium	0.394	old	GDP_3		France	0.229	old	GDP_3	
	Austria	0.372	old	GDP_4		Spain	0.159	old	GDP_3	
	Latvia	0.367	new	GDP_1		Sweden	0.136	old	GDP_4	
	France	0.355	old	GDP_3		Romania	0.014	new	GDP_1	
	Poland	0.347	new	GDP_1		Portugal	-0.094	old	GDP_2	
	Lithuania	0.344	new	GDP_1		C_2	Malta	0.351	new	GDP_2
	Germany	0.343	old	GDP_3			Italy	0.185	old	GDP_3
	Finland	0.292	old	GDP_4			Czechia	0.141	new	GDP_2
	C_2	United Kingdom	0.199	old		GDP_3	C_3	Estonia	0.202	new
Croatia		0.155	new	GDP_1	Finland	0.190		old	GDP_4	
C_2	Italy	0.309	old	GDP_3	Germany	0.174	old	GDP_3		
	Spain	0.301	old	GDP_3	Austria	0.144	old	GDP_4		
	Estonia	0.246	new	GDP_2	Poland	0.129	new	GDP_1		
	Slovenia	0.233	new	GDP_2	Denmark	0.127	old	GDP_4		
	Denmark	0.200	old	GDP_4	Slovenia	0.002	new	GDP_2		
	Czechia	0.048	new	GDP_2	C_4	Luxembourg	0.435	old	GDP_4	
	Portugal	0.032	old	GDP_2		Hungary	0.187	new	GDP_1	
C_3	Netherlands	0.222	old	GDP_4		Netherlands	0.157	old	GDP_4	
	Luxembourg	0.192	old	GDP_4	Ireland	0.059	old	GDP_4		
	Ireland	0.179	old	GDP_4	C_5	Greece	0.000	old	GDP_2	
	Malta	0.131	new	GDP_2		C_6	Croatia	0.000	new	GDP_1

**Note:** 'old' – a state that joined the EU before 2004, 'new' – a state that joined the EU in 2004 or later; 'GDP\_1' – a state with per capita GDP below the first quartile calculated for the EU member states in a particular period, 'GDP\_2' – a state with per capita GDP between the first quartile and the median, 'GDP\_3' – a state with per capita GDP between the median and the third quartile, 'GDP\_4' – a state with per capita GDP above the third quartile. Source: the author's calculations made using the 'NbClust' package in R environment (Charrad et al., 2014) and the 'factoextra' package in R environment (Kassambara and Mundt, 2017).

Positive Silhouette index values obtained for almost all member states prove that the countries were assigned to the clusters in a correct way. Portugal in the years 2011-2017 is an exception. Values close to zero mean that the assignment of such member states as Czechia and Portugal to the C\_2 cluster in 2004-2010, Romania to the C\_1 cluster in 2011-2017, Slovenia to the C\_3 cluster in 2011-2017, and Ireland to the C\_4 cluster in 2011-2017 should be taken with caution.

To assess the similarity of two partitions, the adjusted Rand index was used (ARI = 0.179). The adjusted Rand index suggests that the two partitions (for the periods: 2004-2010 and 2011-2017) are not very similar to each other.

In the next stage of the analysis, the clusters were described. For this purpose, average amounts of public expenditure on particular aspects of environmental protection as a percentage of the GDP were calculated, and the results are shown in Table 3. The highest average amounts of public expenditure on particular aspects of environmental protection are marked in green, while the lowest amounts are marked in red.

**Table 3.** Average amounts of public expenditure on particular aspects of environmental protection as a percentage of the GDP.

Cluster	GF0501	GF0502	GF0503	GF0504	GF0505	GF0506
<b>2004-2010</b>						
C_1	0.278%	0.159%	0.060%	0.034%	0.015%	0.092%
C_2	0.251%	0.166%	0.046%	0.190%	0.040%	0.108%
C_3	0.409%	0.588%	0.119%	0.163%	0.006%	0.030%
<b>2011-2017</b>						
C_1	0.384%	0.093%	0.078%	0.049%	0.016%	0.079%
C_2	0.533%	0.242%	0.046%	0.219%	0.013%	0.037%
C_3	0.096%	0.138%	0.094%	0.078%	0.043%	0.081%
C_4	0.249%	0.393%	0.134%	0.102%	0.007%	0.046%
C_5	0.006%	0.146%	0.003%	0.113%	0.000%	0.300%
C_6	0.621%	0.119%	0.575%	0.005%	0.000%	0.004%

Source: the author's calculations.

The values in Table 3 indicate two clusters of leaders in 2004-2010. In the period 2004-2010, in the C\_2 cluster, the highest average public expenditure was recorded for 'Protection of biodiversity and landscape' (GF0504), 'R&D Environmental protection' (GF0505) and 'Environmental protection n.e.c.' (GF0506). On the other hand, the member states from the C\_3 cluster made the highest average expenditure on 'Waste management' (GF0501), 'Waste water management' (GF0502) and 'Pollution abatement' (GF0503).

In 2011-2017, Greece – forming the C\_6 single-element cluster – dominated in the area of public spending on 'Waste management' (GF0501) and 'Pollution abatement' (GF0503). In turn, Croatia, forming the second single-element cluster C\_5, made the highest public expenditure on 'Environmental protection n.e.c.' (GF0506). The lowest average expenditure on 'Waste water management' (GF0502) was recorded in the C\_1 cluster, while the highest – in the C\_4 cluster. The C\_2 cluster is characterised by the highest average expenditure on 'Protection of biodiversity and landscape' (GF0504). The highest average spending on 'R&D Environmental protection' (GF0505) was recorded for the C\_3 cluster.

In order to profile the clusters, Table 2 presents information about the length of the membership of a given country in the European Union and the level of its economic development.

Based on the analysis of cluster compositions it cannot be unequivocally confirmed that, in the analyzed periods, there was a correlation between the division of the member states of the European Union due to the amounts of funds allocated to various aspects of environmental protection and the division of countries into 'old' and 'new' ones due to the dates of their accession to the European Union, or the division of the member states due to the level of their economic development measured with per capita GDP.

It should be noted, however, that for the years 2004-2010, the C\_2 cluster included mainly the countries with an average level of economic development (per capita GDP between the first quartile and the third quartile), while the C\_3 cluster was dominated by countries with the highest level of economic development (per capita GDP above the third quartile).

In the years 2011-2017, it was noticeable that the C\_1 and C\_3 clusters were dominated by the member states with an above-average level of economic development (per capita GDP

above the median). The C\_2 cluster comprised countries with an average level of economic development (per capita GDP between the first quartile and the third quartile). In contrast, the C\_4 cluster was dominated by countries with the highest level of economic development (per capita GDP above the third quartile). The member states forming the C\_5 and C\_6 single-element clusters were characterised by the level of economic development below the average level recorded for the European Union member states in 2011-2017 (per capita GDP below the median or the first quartile).

#### 4. Conclusions

The findings of the empirical study made it possible to answer the research questions:

1. There was convergence in total public spending on environmental protection in the member states of the European Union in 2004-2017.
2. The structure of the member states in terms of amounts of public spending on various aspects of environmental protection in 2004-2010 differed from the structure of the member states determined for the years 2011-2017.
3. There was no relationship between the structure of countries in terms of amounts of public spending on various aspects of environmental protection in 2004-2010 and 2011-2017 and the length of the membership of these countries in the European Union.
4. There was no unambiguous relationship between the structure of the countries in terms of amounts of public spending on various aspects of environmental protection in 2004-2010 and 2011-2017 and the level of the economic development of these countries. Studies in this area should be continued.

When confronting the conclusions formulated on the basis of the findings of the empirical study with the present knowledge on the analyzed problem, it should be stated that they are:

- consistent as regards the occurrence of convergence in total public spending on environmental protection with the results obtained using the dip-test by Apergis et al. (2013);
- inconsistent as regards the occurrence of convergence in total public spending on environmental protection with the conclusions presented by Ercolano and Romano (2018).

The reasons for the consistency or inconsistency of the conclusions drawn on the basis of this study with the findings of other studies on the occurrence of convergence in total public spending on environmental protection may be seen e.g. in the length of the analyzed period – Apergis et al. (2013) studied a period of 23 years, i.e. 1990-2012; Ercolano and Romano (2018) examined the period of only 9 years, i.e. 2002-2010; and in this analysis it was a period of 14 years, i.e. 2004-2017.

In further studies, the author intends to:

- apply various research approaches to the same data set to check the stability of the analysis findings;

- continue the study following the direction set in Ercolano and Romano (2018), i.e. study the relationship between public spending on environmental protection and some environmental outcomes.

The results of the conducted research enrich the knowledge on the occurrence of convergence in public spending on environmental protection in the European Union countries. Additionally, the results of cluster analysis allow indicating the countries belonging to the European Union, which were similar in terms of the structure of public spending on environmental protection in the years 2004-2010 and 2011-2017. Extend the research to include the assessment of the relationship between public spending on environmental protection and some environmental outcomes should allow finding the optimal model of public spending on environmental protection in the European Union.

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