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The Relationship Between Environmental Performance and Economic Development: Evidence from European Countries*

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Abstract

Building on the fact that without strong efforts to preserve the natural environment and mitigate the consequences of climate change, no development can remain sustainable in the long term, the primary objective of this paper is to investigate the relationship between environmental performance and achieved economic development of selected European countries. For the realization of defined objectives, an innovative (two-stage) research methodology was employed, based on the combined application of cluster analysis and one-way ANOVA. The classification of 38 European countries into distinctive groups, based on the values of three key components of the Environmental Performance Index (EPI) in 2023, was performed using the hierarchical agglomerative clustering procedure. The obtained "optimal" solution, consisting of three clusters, supplemented by the results of the ANOVA-based evaluation of its statistical quality, unequivocally confirms the presence of pronounced disparities among the observed countries in terms of recorded environmental performance. The formed groups with assigned categories (i.e., high, average and low environmental performance) were used as the independent variable in the second stage of the analysis, designed to examine the statistical significance of differences between the average GDP per capita values determined for the three EPI-based clusters of countries. The ANOVA results unequivocally confirm the presence of a positive and statistically significant relationship between achieved economic development and EPI-based environmental

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performance, among the observed European countries in 2023. The obtained research results can provide valuable insights for sustainability policymakers and a better understanding of the nature of the relationship between the economic and environmental performances.

Keywords: *cluster analysis, one-way ANOVA, environmental performance index, GDP per capita, European countries*

JEL classification: *C12, C38, E01, O52, Q56*

1. Introduction

The term *sustainable development* denotes a complex and multidimensional concept, which today, in modern economic and business conditions, is simultaneously understood as the ultimate goal, but also as a means to achieve economic progress while minimizing negative effects on the environment and on society as a whole. In other words, "*sustainable development represents the concept of integrated development of the economic, technological, social and cultural dimensions, balanced with the needs of protection and improvement of the natural environment*" (Veselinović et al., 2023, p. 34). Given the undeniable importance of sustainable development for the long-term survival and progress of humanity, it is not surprising that the international academic and professional community has been interested for decades in finding ways and creating conditions for its establishment at all levels of human organization and economic activity.

The key and strongest stimulus to global efforts aimed at achieving sustainable development was made in September 2015, when the United Nations Assembly adopted the Resolution on Sustainable Development, entitled *The 2030 Agenda for Sustainable Development*, which includes 17 main sustainable development goals (SDGs) and 169 specific goals (Eurostat, 2017). It is necessary to point out that a significant number of SDGs are directly related to the ecological aspects of development, that is, the promotion of a positive environmental impact while achieving economic growth and social progress. Moreover, in parallel with the definition of SDGs, and as part of efforts aimed at achieving them, the need for improving existing and developing new methods for quantifying and precisely measuring the degree of their achievement has arisen. The mentioned need led to the emergence of numerous and diverse diagnostic and benchmarking analytical tools, developed in the form of composite indices, which provide a summary of the state of performance of individual countries and / or regions in the field of achieving individual or a specific group of SDGs.

One of such synthetic indicators, proposed in order to assess the degree of achievement of SDGs related to the environmental performance of individual countries, is the Environmental Performance Index (EPI). In this sense, each individual EPI score represents a carefully designed multivariate quantitative measure of a country's environmental performance that encompasses national progress and efforts invested in protecting the environment (Neagu et al., 2017). Accepting the fact that without preserving the natural environment no development can be sustainable (Chowdhury & Islam, 2017), i.e. that environment and natural resources are the foundation of sustainable development (Samimi et al., 2011; Nguyen et al., 2025), it is not surprising why examining the complex relationship between economic development and environmental performance is of great importance for creators of national (sustainable) development policies and strategies.

The complexity of the aforementioned relationship essentially arises from its nature, which can briefly be described as a "*two-way street*". Actually, intensive fostering of a country's economic growth and development, as a prerequisite for a better quality of life and population's standard of living, necessarily implies, in general, a negative impact on ecosystems, and quality of environmental elements (i.e. land, water, air), thus suggesting that a higher level of a country's economic development is associated with lower environmental performance, and vice versa. At the same time, a higher level of economic development and income allows countries and business entities to invest more in cleaner technologies and renewable energy sources, thereby achieving positive effects in terms of mitigating environmental degradation and climate change consequences. Additional arguments in support of the described complexity can be extracted if developed and developing countries are analyzed separately. These are just some of the reasons why published studies have yielded mixed results and differing conclusions about the nature of the observed relationship.

Therefore, this paper examines the contribution of selected European countries to the achievement of sustainable development goals, from the perspective of recorded environmental performance, as well as the nature of its relationship with their level of economic development in 2023. The objectives of this research are fourfold:

(1) a detailed demonstration of statistically valid combined application of cluster analysis (CA) and one-way ANOVA method in the domain of the defined research subject,

(2) creation of ANOVA-verified classification of selected European countries into certain number of internally homogeneous / externally heterogeneous clusters based on the corresponding values of three key EPI components (i.e. Environmental health, Ecosystem vitality and Climate change) in 2023,

(3) an investigation of the relationship between environmental performance (i.e. categories of the proposed, EPI-based and ANOVA-verified, CA classification) and GDP per capita (as a measure of the achieved level of economic development) for the observed European countries in 2023, and

(4) an interpretation of the characteristics of the formed clusters of countries from the perspective of the used indicators of economic and environmental performances.

In addition, the research hypotheses addressed and tested in this paper are as follows:

> H1: *There are pronounced disparities among the observed 38 European countries in terms of their environmental performance, achieved in 2023.*

> H2: *European countries with higher values of GDP per capita, on average, are characterized by more favorable levels (categories) of environmental performance, recorded in 2023.*

The main novelty of the research presented in this paper lies in the applied (complex) methodological framework, based on the integration of univariate (one-factor ANOVA) and multivariate (cluster analysis) statistical methods, but also in the demonstration of the dual analytical role for which the ANOVA method can be used in the analysis (described in detail in Section 3). In addition, the proposed CA classification of the observed European countries according to selected indicators of environmental performance, together with the results of examining the nature of the relationship between their environmental achievements and economic development, can enhance academic understanding of the analyzed phenomenon, and also provide valuable insights for sustainability policy makers.

Accordingly, the paper is structured as follows. After the Introduction, Section 2 contains the key determinations of EPI, of which sub-indicators were used in the classification of the observed countries, as well as a brief overview of selected empirical studies related to the subject and objectives of this research. Section 3 includes detailed explanation of the methodological framework used, while a description of variables, sources and spatial–temporal coverage of data, as well as the obtained clustering results and ANOVA-based quality evaluation of the proposed classification, are presented in Section 4. Section 5 provides the results of the ANOVA-based investigation of the relationship between environmental performance and GDP per capita for the observed European countries in 2023, as well as a discussion of obtained results. Finally, concluding remarks are given in Section 6.

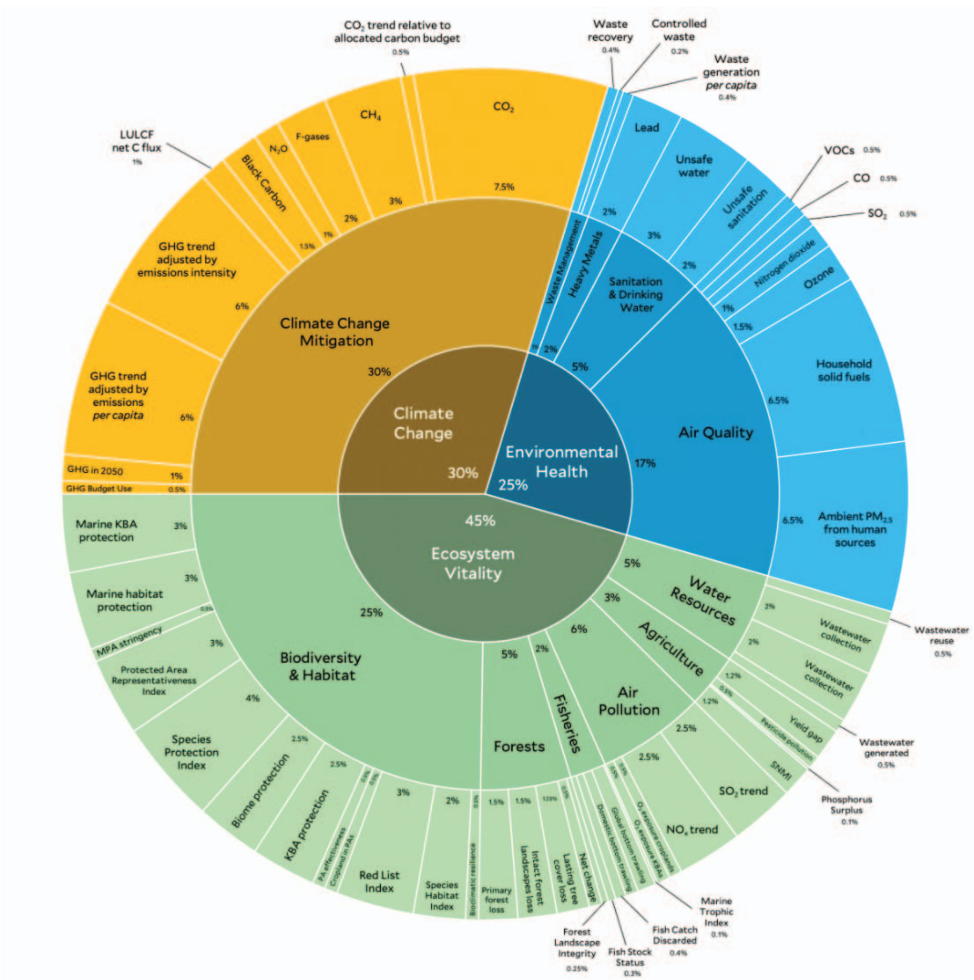
2. Literature review

In this section, a brief overview of selected empirical studies relevant to the observed research area is presented, with special focus on the explanation of main methodological issues regarding the Environmental Performance Index, since its composite scores and sub-indicators' values have a crucial role in the conducted research.

2.1. Environmental Performance Index – key methodological determinations

The Environmental Performance Index (EPI) was created as a result of the joint work of environmental experts and statisticians at the Yale University Center for Environmental Law & Policy and the Columbia University Center for International Earth Science Information Network, with the generous support of the McCall MacBain Foundation. According to its creators, the analytical effort undertaken to develop EPI composite index represents, without exaggeration, the most comprehensive global environmental analysis ever conducted (Wolf et al., 2022, p. XI). The scale and complexity of the aforementioned effort can best be seen through the EPI structure (Figure 1).

Figure 1: Detailed structure of the EPI composite indicator



Source: EPI 2024 Report (Block et al., 2024, p. X)

The EPI index synthesizes information obtained from 58 different indicators of environmental performance, distributed across 11 separate environmental issues. Their aggregated values, after weighting and subsequent aggregation, are used to form the values of the following three key EPI components, which also represent three important goals of sustainable development: *Improving environmental health*, *Protecting ecosystem vitality* and *Mitigating climate change*. The final EPI score, obtained as a result of weighting and aggregating the synthesized values of these three components, represents a composite value (ranging from 0 to 100) that is used to rank 180 countries in terms of their individual performance and progress in the field of achieving sustainable development and meeting the set sustainability goals, but also providing a summary of the situation at regional and global level in the domain of the aforementioned issue. The EPI and its components provide a list of comparable numerical values that allows for the separation of leading countries and those lagging behind in terms of achieved environmental performance and, based on the possibility of comparison, provide practical guidelines for countries striving for a sustainable future and meeting the SDGs (Block et al., 2024).

2.2. Research background

Examining the relationship between differently structured socio-economic and environmental dimensions of development in selected groups of countries represents a highly attractive research niche among members of the scientific community. The great interest of researchers in the mentioned analytical area, measured by the number of published empirical studies, is not surprising, given the importance of achieving and monitoring the level of realization of SDGs at the level of national economies in the modern global economic environment. In this context, different variables were used as adequate representatives of socio-economic (e.g. level of education, population density, Human Development Index [HDI], Quality of Life Index, GDP per capita or growth rate, etc.) and environmental dimension (e.g. CO_2 emission, Environmental Sustainability Index, Human Sustainable Development Index, Sustainable Development Goals Index, Environmental Performance Index [EPI], etc.). In accordance with the research objectives in this paper, in Table 1, the key methodological determinants of selected empirical studies of a similar research character, based on the use of EPI and / or its components, as proxy variables of the environmental development dimension, are presented.

Table 1: List of selected empirical studies on dependency / interdependency between EPI and economic performance indicator(s)

No.	Author(s) / (year)	Temporal coverage	Spatial coverage	Methodology approach
1.	Samimi et al. (2010)	2008	20 developing countries	WLS multiple regression analysis
2.	Samimi et al. (2011)	2006–2010	114 countries worldwide	GLS panel data regression analysis
3.	Duasa & Afroz (2013)	2010	all countries listed by the UN	OLS & GMM multiple regression analysis
4.	Bucher (2016)	2014	43 European countries	Hierarchical clustering & regression analysis
5.	Neagu et al. (2017)	2016	166 countries worldwide	Quadratic simple regression analysis
6.	Chowdhury & Islam (2017)	2008–2016	5 BRICS countries	Simple correlation analysis
7.	Fakher & Abedi (2017)	1983–2013	selected developing countries	ARDL model, co-integration & causality tests
8.	Sinevičienė et al. (2018)	2000–2010	15 developing countries (Europe)	GLS panel data multiple regression analysis
9.	Gallego-Álvarez et al. (2018)	2008	24 countries in Latin America	PCA & multiple regression analysis
10.	Lukáč et al. (2020)	2008–2018	38 selected OECD countries	PCA & hierarchical cluster analysis
11.	Boleti et al. (2021)	2002–2012	88 selected OECD countries	OLS panel data multiple regression analysis
12.	Repiská et al. (2022)	2018	15 selected EU countries	Hierarchical cluster analysis
13.	Dima et al. (2024)	2023	167 countries worldwide	Geographically weighted multiple regression
14.	Ristić & Gavrić (2024)	2022 (2023)	27 EU countries	Correlation & hierarchical cluster analysis
15.	Saraiva & Caiado (2025)	mainly 2020	206 countries worldwide	Non-hierarchical cluster analysis & PCA
16.	Karountzos et al. (2025)	2023	123 countries worldwide	Correlation and multiple regression analysis

Source: Authors' representations

A detailed analysis of the content of research studies in Table 1 additionally confirms the expressed variability in terms of analytical scope (spatial and temporal), implemented methodological approach, as well as the selection of indicators used to measure the level of socio-economic development, regardless of the unification of environmental variables. In the methodological context, compared to the recorded rare cases of implementation of correlation and cluster analysis, the application of different types of multiple regression (econometric) analysis can be singled out as dominant, with differences regarding the role (dependent or independent) assigned to environmental variables. The described variability, consequently, did not bypass the results and conclusions of studies based on the applied regression analysis. More precisely, the statistically significant impact of GDP per capita or another indicator of economic development (e.g. HDI or GDP growth rate) on environmental performance (measured by the EPI scores or values of its key components), as dependent variable, was confirmed in studies, listed in Table 1, with the following ordinal numbers: 2, 3, 5, 8, 9, 11. And while in most cases the statistical significance of the positive impact of used economic indicators on the environmental (EPI, dependent) variable has been proven, Gallego- Álvarez et al. (2018) confirm the presence of a negative and statistically significant impact of GDP per capita, in the case of 24 selected Latin American countries.

Similar results, but in the case of 86 developing countries and using HDI as an independent variable in the model, were also presented by Samimi et al. (2011), contrary to the research conducted by Bucher (2016), whose results suggest the absence of a statistically significant impact of HDI on EPI variable. In contrast, the studies conducted by Karountzos et al. (2025), Dima et al. (2024), Fakher and Abedi (2017), and Samimi et al. (2010) provide empirical evidence supporting the existence of a positive and statistically significant impact of environmental quality, measured by the EPI (serving as the explanatory variable), on economic performance, measured by GDP per capita or real GDP growth rate.

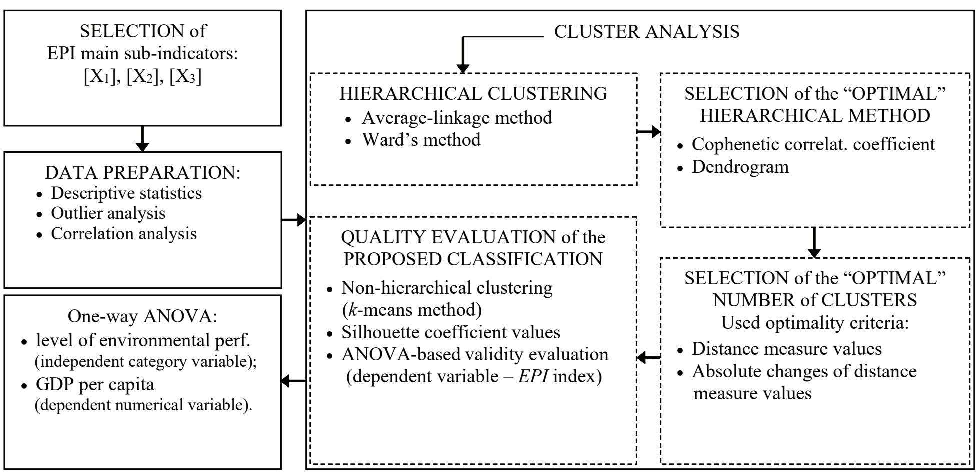
Although the existing literature provides valuable insights into the relationship between environmental performance and economic development, several limitations remain evident. Most previous studies rely predominantly on regression-based approaches and focus on examining direct causal relationships between used indicators. Consequently, less attention has been devoted to identifying homogeneous groups of countries according to environmental performance and to analyzing economic disparities between such groups using integrated multivariate statistical procedures. These limitations indicate the existence of a research gap that justifies the application of alternative methodological approaches.

In this context, the originality of the conducted research lies primarily in the statistically valid implementation of a specific methodological framework, based on the combined application of hierarchical cluster analysis and the ANOVA method for the purpose of examining the relationship between GDP per capita and achieved environmental performance. According to the authors' knowledge, the applied combination of temporal-spatial data coverage, statistical approach and variables, as relevant indicators of economic and environmental dimensions of development, has not been exploited in the existing literature so far in the analysis of this research problem. Beyond its methodological contribution, the study also provides a theoretical contribution to the existing literature by enriching the understanding of the nature of the relationship between economic and environmental performance, particularly in the context of European economies. It is expected that the presented results will contribute to the advancement of theoretical knowledge within this research niche by offering additional empirical evidence and supporting a more refined interpretation of the economic–environmental nexus. Moreover, regardless of the similarity of research objectives, the results obtained in studies listed in Table 1, generally, cannot be considered directly comparable to the results presented here, due to the existence of analytical-methodological differences outlined above.

3. Methodology

A schematic representation of the methodological framework used, supplemented by detailed explanations of the applied statistical methods and their key determinants, is given in Figure 2.

Figure 2: Schematic representation of the used research methodology framework



Source: Authors' representation

Cluster analysis is a generic term used to describe a wide range of multivariate statistical procedures specifically designed to reveal "*natural*" structure, i.e.

classification of observation units, within complex and heterogeneous data sets (Gore, 2000; Stamenković et al., 2021). Drawing on the essential definitions of the proximity concept, the common primary goal of these procedures is to divide a given set of multivariate observations into an a priori unknown but typically small number of mutually exclusive and, to the greatest extent possible, internally-homogeneous and externally-heterogeneous, meaningful groups, known as clusters (Stamenković & Milanović, 2022). Actually, the outcome of any clustering procedure is a classification structure made up of a certain number of clusters, where observations within the same group are considered to have "*high*" mutual similarity (i.e. proximity), but also "*low*" similarity with observations within other clusters, in terms of the values of simultaneously analyzed variables (Bijnen, 1973).

In this context, after thorough data preparation of the selected key EPI components, CA was used to extract a classification of the analyzed countries according to their recorded level of environmental performance. Within this phase, CA plays the role of the central method, while ANOVA is used as an auxiliary method for evaluating the quality of the proposed clustering solution. From a methodological perspective, the application of CA is characterized by several specific features. The optimal hierarchical clustering method and the appropriate number of clusters within the obtained tree-classification structure were selected using objective statistical criteria, thereby reducing subjectivity in the clustering procedure. In addition, the results of hierarchical (HCA) and non-hierarchical (Non-HCA) clustering methods were comparatively evaluated using silhouette coefficient values in order to identify the most reliable classification of countries. In applying ANOVA, the role of the dependent variable was assigned to the final EPI scores, while the clusters in the proposed classification structure were used as individual categories of the independent variable. In the next research phase, the one-way ANOVA method was re-applied, this time as the central analytical method, in order to examine the statistical nature of the relationship between the level of economic development, measured by GDP per capita, and environmental performance, represented by separate groups in the proposed CA classification (as categories of independent variable), using selected European countries as the research sample. The purpose of this research step is to test the hypothesis regarding the presence of statistically significant differences in average GDP per capita values among clusters of European countries representing different levels of environmental performance. The practical demonstration of the dual analytical role of ANOVA within the same research framework represents one of the key methodological contributions of the conducted research.

The analysis of the collected data and all necessary statistical calculations were performed using IBM-SPSS Statistics version 21 and Microsoft Office Excel. The interpretation of the obtained results is complemented by appropriate tabular, cartographic, and statistical graphical representations.

4. Empirical data and analysis

In this section, we present the research aspects related to the selected environmental performance variables, the sources used, and the spatial–temporal scope of empirical data, together with the preliminary data analysis and the results of CA-based and ANOVA-verified classification of analyzed countries according to their environmental performance.

4.1. Variables, sources of data, and temporal-spatial scope of the research

For the realization of defined objectives, and in accordance with the methodological framework, secondary data of different sets of numerical variables from different sources were collected. For the CA-based classification of observation units in terms of various aspects of achieved environmental performance, data on the three key EPI components (i.e. Environmental health, Ecosystem vitality, Climate change) were used, while the ANOVA-based evaluation of its quality was carried out using the *composite EPI scores* as the dependent variable. The source of data for these environmental variables is the *2024 Environmental Performance Index Report* (Block et al., 2024, p. 11). Additionally, the ANOVA-based evaluation of the relationship between economic and environmental performances was conducted using GDP per capita (expressed in constant 2021 international dollars, converted by purchasing power parities – PPPs) (International Monetary Fund [IMF], 2024), as dependent variable – an indicator of economic development, and created groups of countries, as individual categories of (independent) environmental variable. The last available data for all analyzed variables refer to 2023. The observation units include the following 38 European countries: 27 EU member states, 6 candidate countries and potential candidates for EU membership (Serbia, Montenegro, North Macedonia, Moldova, Albania, Bosnia & Herzegovina) and 5 countries that are not part of the EU by their own decision (Iceland, Norway, Great Britain, Belarus, Switzerland).

4.2. Classification of European countries by the main EPI components

In order to classify the analyzed European countries into an appropriate number of internally-homogeneous and externally-heterogeneous clusters, in terms of their achieved environmental performance, a hierarchical agglomerative cluster analysis was conducted using the three key EPI components. The normalization procedure for the input variables was not applied, since their values result from the aggregation of previously normalized and weighted values of a large number of original indicators included in the multivariate EPI structure (Figure 1), and therefore range from 1 to 100 index points. The values of the arithmetic mean ($\bar{x}$), median (m_e) and coefficient of variation (v) for the used input variables are presented in Table 2.

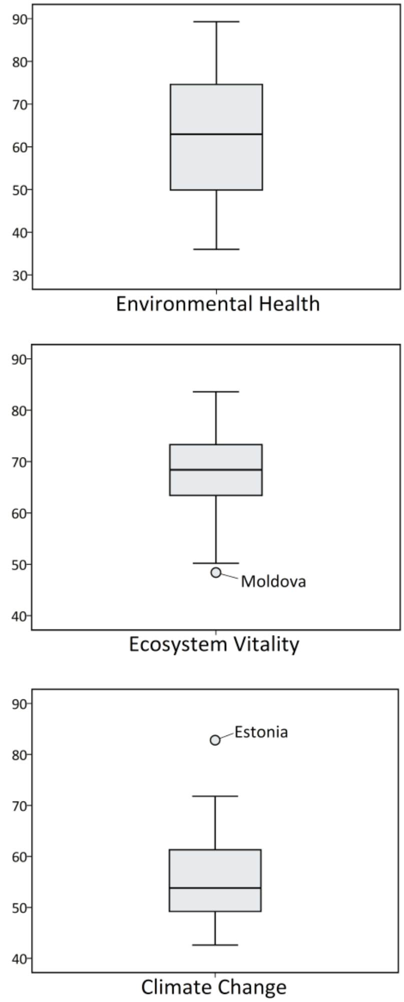
Table 2: Values of key descriptive statistical measures of EPI components

EPI sub-indicators		$\bar{x}$	m_e	v
Environmental health	(X_1)	62.77	62.95	23.4%
Ecosystem vitality	(X_2)	67.51	68.40	12.9%
Climate change	(X_3)	55.79	53.80	16.3%

Source: Authors' calculations

Within the preparation phase and preliminary data analysis, the detection of a possible presence of univariate and multivariate atypical observations (i.e. outliers) was carried out, using box-plots and Mahalanobis distance measure values, respectively. Constructed diagrams for individual variables (Figure 3), as well as the approximate values of their positional (m_e) and calculated ($\bar{x}$) measures of central tendency, unequivocally suggest the absence of true one-dimensional outliers. One *"suspected"* non-standard observation was detected for each of the variables X_2 [MDA] and X_3 [EST]. It is also important to emphasize that Estonia represents a multivariate outlier, since it is characterized by a Mahalanobis distance measure value (MD_{EST} = 11.665) which is significantly above the corresponding critical value of the chi-square distribution, i.e. $\chi^2_{(3;\ 0.975)} = 9.348$. Elimination of this multivariate observation from further analysis was not carried out, since it represents an extremely small and very significant part of the available data set, especially in terms of territorial data coverage. Finally, since the values of the relative measure of dispersion (v) for all three variables are lower than 30%, it is clear that there is a relative homogeneity of the data in their distribution, with the lowest variability among the analyzed countries being recorded in the case of variable X_2 (i.e. $v_2 = 12.9\%$).

Figure 3: Box-plots for individual EPI components

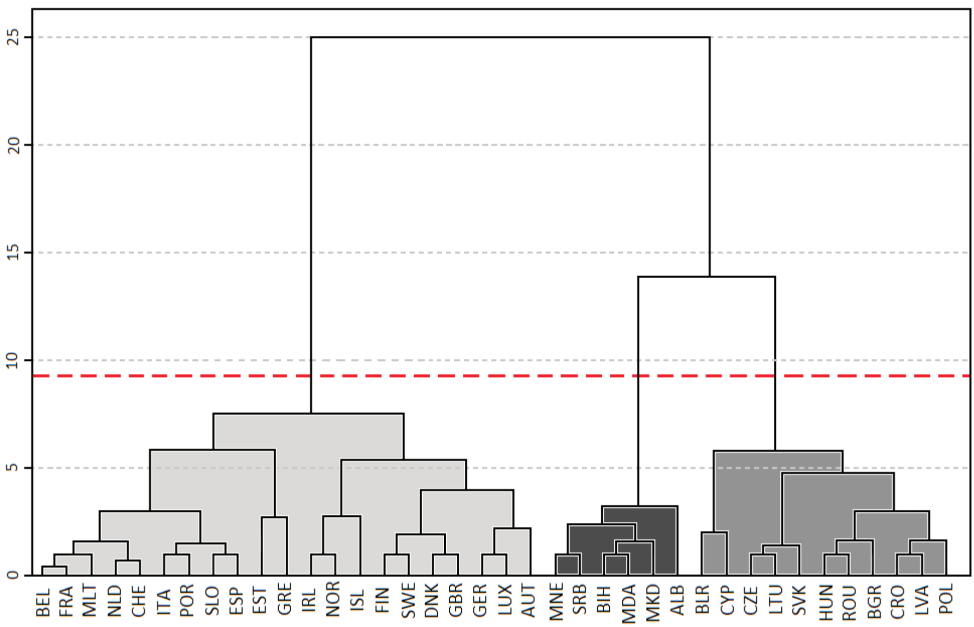


Source: Authors' calculations

In addition to the above, the results of a simple linear correlation analysis suggest the absence of a very strong interdependence of the variables, since the correlation coefficient values (r) range from $r_{x_2x_3} = 0.391$ to $r_{x_1x_3} = 0.506$. The results of the hypothesis testing procedure for the parameter ρ confirmed the statistical significance of the linear correlation in the case of all three pairs of analyzed variables.

On preprocessed multivariate data of three key EPI components, a hierarchical agglomerative classification procedure was implemented, based on the application of Average-linkage and Ward's method, using squared Euclidean distance as the appropriate distance measure. Given that it is characterized by a higher value of Cophenetic correlation coefficient (CpCc = 0.592), but also by a more visually acceptable classification structure of European countries, the Ward's method was chosen as optimal, against the (alternative) Average-linkage method (CpCc = 0.591). A graphical display of the hierarchical grouping results of analyzed 38 countries according to EPI components, in the form of a dendrogram, is presented in Figure 4.

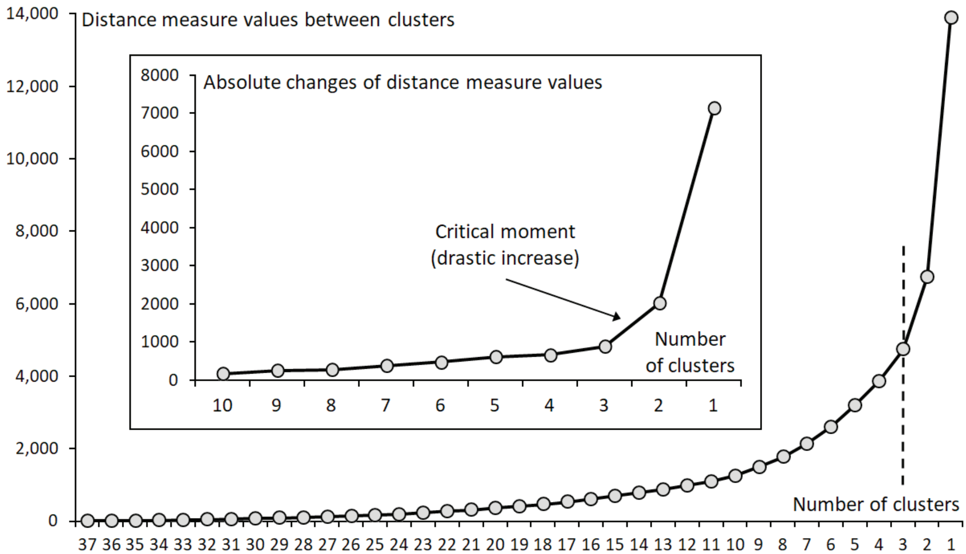
Figure 4: Graphical representation of the obtained hierarchical structure



Source: Authors' calculations

Three visually distinctive groups in the structure of the complete hierarchical tree on the dendrogram are marked with different shades of gray. Statistical verification of this subjective statement made by authors, i.e. the selection of the "*optimal*" number of clusters, was performed using the criteria presented in the methodological framework. Graphical representations of the movement of distance measure values between countries and/or groups of countries and their absolute increase in successive steps of the agglomeration process are presented in Figure 5.

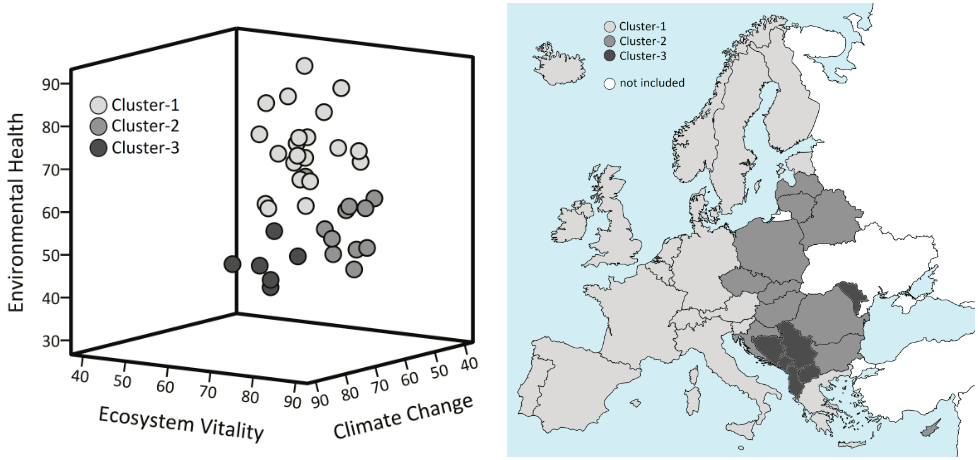
Figure 5: Graphical display of values and increments of distance measure between groups



Source: Authors' calculations

In Figure 5, a sudden interruption of the continuous and gradual increase in the value of distance measure between the formed groups, as well as its absolute increase, which occurred in the 36th step of the agglomeration process at the moment of extracting a classification solution that includes two clusters. is clearly visible. Since the observed drastic increase in the optimality criteria suggests the merging of highly heterogeneous groups, the solution that precedes the described changes (i.e. the three-cluster solution) stands out as the optimal clustering solution. Additional (graphical) confirmation of the selected hierarchical solution is given in Figure 6 and the distribution of countries by extracted groups in Table 3.

Figure 6: Visual representations of environmental classification of selected European countries



Source: Authors' representations

Table 3: Distribution of European countries by extracted clusters

Cluster code	Environmental performance	No. of countries	Countries within individual clusters
c-1	"*high-level*"	21	GBR, IRL, ISL, BEL, NLD, LUX, CHE, GER, FRA, DNK, FIN, SWE, NOR, EST, ITA, GRE, MLT, ESP, POR, SLO, AUT
c-2	"*average-level*"	11	LTU, LVA, POL, BLR, SVK, CZE, HUN, ROU, BGR, CRO, CYP
c-3	"*low-level*"	6	ALB, MNE, BIH, MKD, SRB, MDA

Source: Authors' calculations

Additional quantitative verification of the proposed classification is obtained by comparing values of the silhouette coefficient, as a statistical measure intended for a comprehensive evaluation of the quality of the obtained clustering results, calculated for hierarchical and non-hierarchical classification structures. More precisely, the overall silhouette coefficient value ($\overline{\overline{silh}}$ = 0.629), calculated for the hierarchical classification, is clearly higher than the comparable value of the non-hierarchical alternative ($\overline{\overline{silh}}$ = 0.526), thus indicating that the created hierarchical solution is characterized by higher quality.

4.3. ANOVA-based validity evaluation of the proposed classification

Evaluation of validity and practical significance of the CA classification was conducted by implementing one-way ANOVA and testing the following statistical hypotheses:

> H0: *There is no statistically significant difference between the average EPI scores for the observed three groups of countries;*
>
> H1: *There is a statistically significant difference between the average EPI scores for at least two groups of countries.*

The identified level of environmental performance for individual clusters represents an independent (categorical) variable with 3 treatments [c-1 (high-level); c-2 (average-level); c-3 (low-level)], while EPI represents the dependent (continuous numerical) variable. Based on the dependence of final EPI scores on its 3 components' values, used in CA as input variables, the validity of the proposed classification will be confirmed if there is sufficient empirical evidence to reject H0 hypothesis. Since ANOVA is a parametric method, the normality of dependent variable's distribution across the selected groups of countries was tested using the Anderson-Darling test. The obtained results (Table 4) suggest that there is not enough evidence to reject the null hypothesis about the normality of the dependent variable's distribution in case of all three clusters of countries, since the resulting p-values are higher than defined significance level, $\alpha = 0.05$. The normality of EPI distribution by clusters is expected, given the absence of univariate (true) outliers within them (Figure 7-left). The fulfillment of the assumption regarding the homogeneity of population variances was also confirmed by the results of the Levene's test (i.e. test statistic = 0.848, with resulting p-value (0.437) > $\alpha = 0.05$).

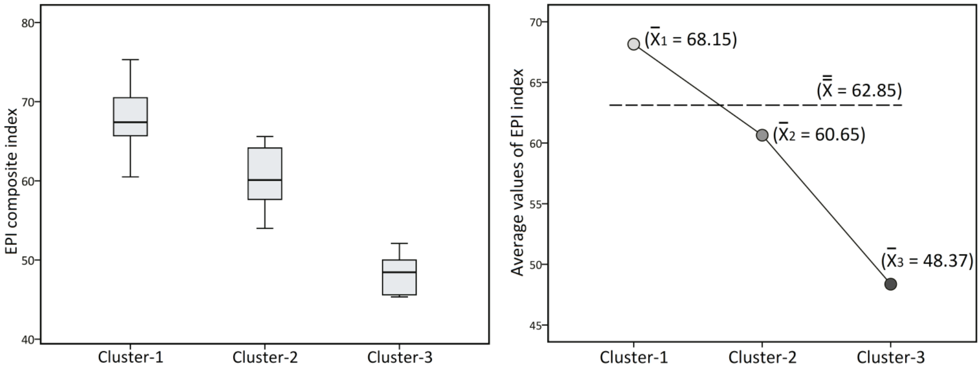
Table 4: Results of EPI distribution normality testing

Dependent variable (Y_i)	Categories of independent variable	Anderson-Darling test	
		statistics	p-values
EPI	cluster-1	0.330	0.488
	cluster-2	0.294	0.533
	cluster-3	0.248	0.599

Source: Authors' calculations

After a detailed check and confirmation that all key assumptions were met, a one-way ANOVA was conducted to make a decision regarding the defined statistical hypotheses, Since the realized test significance level (p-value = 0.000), for the calculated value of the F test statistic ($F_{(\alpha = 0.05;\ v1 = 2;\ v2 = 35)} = 59.644$), is lower than the defined significance level ($\alpha = 0.05$), it can be concluded that there is enough empirical evidence to reject H0 and accept the alternative H1 hypothesis, claiming that there is a statistically significant difference between the average EPI scores of at least two of three groups of countries, separated according to the level of environmental performance.

Figure 7: Box-plots (left) and means plot (right) of EPI variable for individual clusters



Source: Authors' calculations

To identify specific clusters of countries between which there is a statistically significant difference in the arithmetic means of the dependent EPI variable, a multiple comparison of all possible pairs of independent variable categories was conducted using the Fisher's Least Significant Difference (LSD) post-hoc test (Table 5).

Table 5: Results of the Fisher's LSD post-hoc test

Categories of independent variable	Clusters for comparison	Means differences	p-values
cluster-1 ("*high-level*")	cluster-2	7.502	0.000
	cluster-3	19.781	0.000
cluster-2 ("*average-level*")	cluster-1	–7.502	0.000
	cluster-3	12.279	0.000
cluster-3 ("*low-level*")	cluster-1	–19.781	0.000
	cluster-2	–12.279	0.000

Source: Authors' calculations

The results of post-hoc analysis suggest, with the Bonferroni corrected test significance level ($\alpha^* = 0.0083$), that there is a statistically significant difference between all three categories (clusters) of European countries in terms of the corresponding average EPI scores (Figure 7-right), thus confirming the validity and practical significance of proposed CA classification.

5. Results and discussion

This section focuses on an ANOVA-based investigation of the interdependency between economic and EPI performances, using the previously formed CA classification of European countries and GDP per capita as relevant input variables, and discusses the obtained results.

5.1. ANOVA-based evaluation of the relationship between economic and EPI performances

To examine the nature of the relationship between economic development and environmental performance levels of 38 European countries in 2023, a one-way ANOVA was applied to test the following statistical hypotheses:

> H0: *There is no statistically significant difference between the average GDP per capita values for the observed three EPI-based clusters of countries;*
>
> H1: *There is a statistically significant difference between the average GDP per capita values for at least two EPI-based clusters of countries.*

The identified environmental performance level of individual groups represents an independent (categorical) variable with 3 categories [c-1 (high-level); c-2 (average-level); c-3 (low-level)], while GDP per capita is the dependent (continuous numerical) variable. The assessment of assumption validity for ANOVA revealed the presence of one true outlier [LUX], in terms of GDP per capita, within the group of countries characterized by high environmental performance (Figure 8-left). The presence of the outlier affected the results of testing the hypotheses about the normality of GDP per capita distribution for individual clusters (Table 6, columns III-V). For eliminating negative effects, [LUX] was removed from further analysis. The results of the repeated normality testing procedure are given in Table 6 (columns VI-VIII).

Table 6: Results of GDP per capita distribution normality testing

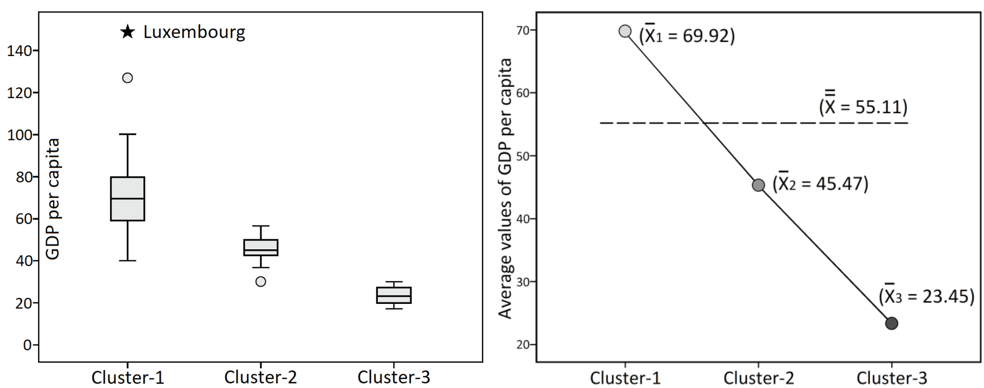
Dependent variable (Y_i)	Categories of independent variable	38 European countries			without Luxembourg (outlier)		
		Anderson-Darling test		Decisions	Anderson-Darling test		Decisions
		statistics	p-values		statistics	p-values	
GDP per capita	Cluster-1	0.987	0.011	H_1	0.496	0.189	H_0
	Cluster-2	0.224	0.764	H_0	0.224	0.764	H_0
	Cluster-3	0.264	0.546	H_0	0.264	0.546	H_0

Source: Authors' calculations

The obtained results suggest that there is not enough evidence to reject the null hypothesis about the normality of GDP per capita distribution in case of all three clusters of countries, since the resulting p-values are higher than the defined significance level, $\alpha = 0.05$.

The ANOVA results suggest that there is sufficient empirical evidence to accept the alternative hypothesis, claiming that there is a statistically significant difference between the average GDP per capita values of at least two groups of countries, separated according to their environmental performance level, since the p-value (0.000), obtained for F test statistic ($F_{(\alpha = 0.05;\ v1 = 2;\ v2 = 34)} = 22.982$), is less than the defined level of test significance ($\alpha = 0.05$).

Figure 8: Box-plots (left) and means plot (right) of GDP per capita for individual clusters



Source: Authors' calculations

To identify specific clusters of countries between which there is a statistically significant difference in the arithmetic means of the dependent GDP per capita variable, a multiple comparison of all possible pairs of independent variable's categories was conducted using the Games-Howell post-hoc test (Table 7), since the assumption of population variances homogeneity was not confirmed by the Levene's test results (statistic = 3.324, p-value (0.048) < $\alpha = 0.05$).

Table 7: Results of Games-Howell post-hoc test

Categories of independent variable	Clusters for comparison	Means differences	p-values
cluster-1 (“*high-level*”)	cluster-2	24.444	0.000
	cluster-3	46.469	0.000
cluster-2 (“*average-level*”)	cluster-1	–24.444	0.000
	cluster-3	22.025	0.000
cluster-3 (“*low-level*”)	cluster-1	–46.469	0.000
	cluster-2	–22.025	0.000

Source: Authors’ calculations

The obtained post-hoc analysis results suggest, with the Bonferroni corrected test significance level ($\alpha^* = 0.0083$), that there is a statistically significant difference between all three pairs of categories (clusters) of European countries in terms of the corresponding average GDP per capita values. Figure 8 (right) visually confirms the interpreted ANOVA results.

5.2. Interpretation of the relationship between economic and EPI performances

Starting from the presented outcomes of the twofold ANOVA application, based on the proposed CA classification, as well as a comparative overview of the mean values of EPI and GDP per capita by the formed clusters of European countries (Table 8), the interpretation and discussion of the overall examination results of the relationship between economic development and environmental performance, for the observed countries in 2023, were carried out in the context of formulated research hypotheses. In this sense, the following observations can be made:

● Within the cluster of countries characterized by a high level of environmental performance, the presence of EU countries that gained membership before 2000 is dominant, along with non-EU Western European countries. This classification outcome is fully expected and confirms the analytical power of CA and the practical importance of the proposed typology, since the listed 21 countries are positioned in the first 29 places in the EPI world ranking in 2023 (Block et al., 2024). Cluster named “*average level of environmental performance*” includes all remaining EU countries, which gained membership in enlargement waves after 2000, and [BLR] as a non-EU country. Finally, all 6 candidate countries and potential candidates for EU membership are allocated within cluster-3. Generally, these are the worst positioned European countries in terms of recorded environmental performance in 2023, both according to the classification results and EPI world ranking, where they occupy positions above 50th place.

Table 8: Comparative overview of EPI and GDP per capita mean values by clusters in 2023

Clusters' size	Environmental performance	Averages	
		EPI	GDP pc
$n_1 = 21$	high-level	68.1	73.67
$n_2 = 11$	average-level	60.6	45.47
$n_3 = 6$	low-level	48.4	23.45
Total mean values	$m_o = m_e$ = high-level	$\bar{x} = 62.9$	$\bar{x} = 57.58$

Note: m_o (mode), m_e (median), $\bar{x}$ (arithmetic mean).

Source: Authors' calculations

- The regularity observed in the distribution of average EPI scores by clusters of analyzed countries (Table 8, column 3) fully justifies assigned descriptive names to them, regarding their level of environmental performance in 2023 (Table 8, column 2). The highest average EPI score is held by countries in cluster-1, while the lowest average is reserved for members of cluster-3. The difference in their EPI averages of approximately 40% clearly indicates the extent of disparities present between the countries in these groups in terms of environmental performance in 2023. The average EPI score of cluster-2 is 12.5% below the corresponding value of cluster-1, that is, 25% above the EPI average of cluster-3 and close but slightly below the EPI average of all 38 countries. Compared to the EPI average in the entire sample (62.9), the average of cluster-1 is 8.5% (or nearly 5 points) above, while the corresponding value of cluster-3 is 23% (≈15 index points) below the comparable sample value. The described practical and, according to the ANOVA results, proven statistical significance of differences between the EPI averages of the three clusters in the structure of the highly interpretable CA classification, indicate the presence of pronounced disparities in terms of recorded environmental performances of the observed European countries in 2023. Consequently, it can be concluded that the validity of the first research hypothesis has been confirmed.

- The ranking of clusters according to average GDP per capita (Table 8, column 4) is completely identical to their ranking in terms of environmental performance. It is evident that the countries distributed within cluster-1 (i.e. high environmental performance) also recorded the highest GDP per capita average (i.e. high level of economic development), and vice versa in the case of cluster-3 (the lowest environmental performance and GDP per capita average), while cluster-2 is characterized by averages of EPI and GDP per capita, generally, between the previous two groups. The statistical significance of differences in average GDP per capita values between all three clusters of European countries, formed according to environmental performance, is clearly proven by the results of the ANOVA-based post-hoc analysis, and thus the validity of the second research hypothesis, claiming that European countries with higher GDP per capita values, on average, are characterized by more favorable levels of environmental performance, recorded in 2023, is indisputably confirmed.

Although direct comparability of obtained research results with published empirical studies is not fully feasible or valid due to methodological differences and "*limitations*", apostrophized in Section 2, the identification of a "*positive*" statistically significant relationship between economic development (measured by GDP per capita) and environmental performance levels in this paper, in general, confirms the findings and conclusions made by Duasa and Afroz (2013), Neagu et al. (2017), Sinevičienė et al. (2018), Boleti et al. (2021). The common denominator of the research approaches by mentioned authors is the application of multiple regression analysis and the use of EPI (or its main components) as a dependent variable. In addition, Karountzos et al. (2025), Dima et al. (2024), Fakher and Abedi (2017) and Samimi et al. (2010) also confirm the existence of a positive statistically significant relationship between the observed development dimensions, but, contrary to previous studies, they used EPI as an independent variable in the regression models, examining its impact on GDP per capita or GDP growth rate, as dependent variables. Ristić and Gavrić (2024) came to similar findings, investigating the correlation between EPI variations and the Legatum Prosperity Index (as an indicator of quality of life and economic wealth) for 27 EU countries, using hierarchical cluster and correlation analysis. On the other hand, Samimi et al. (2011) and Repiská et al. (2022) also presented empirical evidence in support of the existence of a positive statistically significant relationship between the economic and environmental performance of the analyzed countries, but using HDI as an indicator of economic development instead of GDP per capita.

These findings suggest that environmental performance is closely associated with the level of economic development, indicating that higher-income countries are generally more capable of investing in environmental protection, technological innovation, and institutional capacity for implementing environmental policies. At the same time, the observed clustering pattern implies that economic development and environmental quality are not isolated dimensions but tend to co-evolve within similar structural and institutional frameworks. This reinforces the importance of integrated policy approaches that simultaneously address economic growth and environmental sustainability, particularly in the case of less developed countries aiming to converge towards higher environmental performance standards.

6. Conclusions

In this paper, according to the defined subject and the research objectives, a two-stage statistical framework was conducted (based on the combined application of hierarchical agglomerative clustering procedure and one-way ANOVA in a dual analytical role), which primarily focused on the investigation of the relationship between environmental performance (determined as categories of the proposed EPI-based CA classification) and achieved economic development (measured by GDP per capita) on the example of 38 European countries in 2023. In this context, the results of the hierarchical (ANOVA-verified) classification, obtained using the representative values of three key EPI components, in the first research phase, unequivocally confirm the presence of pronounced disparities among the observed European countries in terms of recorded environmental performance in 2023, since the solution that includes three clusters was singled out as optimal. The formed clusters of European countries, with assigned descriptive names that reflect their rank in terms of environmental performance level (i.e. high, average, low), were used as a categorical independent variable in the second research phase, aimed at testing the validity of the second research hypothesis that claims: European countries with higher GDP per capita, on average, are characterized by more favorable categories of environmental performance, recorded in 2023. The ANOVA-based results, within the second research stage, unequivocally confirm the presence of a positive statistically significant relationship between the achieved economic development level and EPI-based environmental performance.

The interpretation of the clusters' profiles, based on the comparison of corresponding EPI and GDP per capita averages, also reveals another categorical component (named by the authors as *EU membership*), which can be seen as a possible cause of the present eco-disparities. It also supports the statistical significance of the identified positive relationship, considering its indirect relation with the level of economic development of the analyzed European countries. Actually, based on the average EPI and GDP per capita values, the formed clusters can be ranked as follows: cluster-1 (dominant presence of "*older*" EU members) > cluster-2 (dominant presence of "*newer*" EU members) > cluster-3 (candidates and potential candidates for EU membership). The possible cause of the aforementioned ranking may be the countries' EU membership and the length of that membership. Actually, due to the numerous economic and market benefits it brings, EU membership gives countries greater opportunities for faster economic development.

Logically, the economic development of EU countries is directly related to the length of their membership. In addition, quite a long tradition in terms of adopting and implementing legislation aimed at establishing a green economy and achieving SDGs is an inherent characteristic of the EU, in relation to countries beyond its borders. Consequently, the "*older*" EU countries have a significant head start and greater experience in achieving SDGs, but also a better economic basis for investing in cleaner technologies and renewable energy sources, or relocating eco-risky ("*dirty*") industries outside their borders, thereby achieving positive effects in mitigating environmental degradation and climate change consequences, compared to countries that joined the EU later on or not at all. In general, from the perspective of European countries, EU membership represents a necessary step in ensuring better conditions for achieving sustainable development. This interpretation contributes to the theoretical understanding of the economic–environmental nexus by highlighting the importance of supranational institutional frameworks, such as the EU, as a structural factor influencing the co-evolution of economic development and environmental performance. In this sense, EU membership is not only a formal status, but also a channel through which institutional quality, regulatory experience, and sustainability-oriented policies are progressively internalized, thereby strengthening the link between the observed development dimensions.

Furthermore, the obtained research results can provide valuable insights for sustainability policymakers, while the proposed methodological framework can serve as a suitable basis for assessing the current situation and monitoring future changes (progress or deterioration) in the positions of the observed countries with regard to their environmental performance, thereby supporting efforts aimed at mitigating existing disparities. In this context, the proposed methodological framework represents the main practical contribution of the study, as it can also be applied to a broader set of countries.

The present study is subject to several limitations that should be acknowledged. First, the analysis is based on cross-sectional data for a single year (2023), which does not allow for the capturing of dynamic changes or long-term temporal relationships between economic development and environmental performance. Second, although the EPI represents a comprehensive and widely used measure of environmental quality, it remains a composite indicator and is therefore subject to limitations inherent in the aggregation procedures and weighting schemes of its constituent components. Finally, the relatively limited degree of direct comparability of the obtained results with findings from previously published studies should also be noted, due to differences in methodological approaches, data sources, and sample selection.

Future research could extend the proposed methodological framework in several directions. A natural extension would involve incorporating a longitudinal dimension through a panel data analysis in order to capture the dynamic evolution of the relationship between economic development and environmental performance over time. In addition, future studies could include alternative measures of environmental quality and economic development, such as the ecological footprint, CO_2 emissions, or HDI, in order to test the robustness of the obtained results. Furthermore, the analysis could be expanded beyond the European context to include a broader set of countries at different stages of development, thereby enabling a more comprehensive global comparison. Finally, future research could incorporate regression techniques applied to individual country clusters formed on the basis of EPI sub-indicators, with the aim of examining the strength of the impact of EPI as an explanatory variable on GDP per capita as the dependent variable.

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Odnos između ekološke učinkovitosti i gospodarskog razvoja: dokazi iz europskih zemalja

Milan Stamenković[1], *Marina Milanović*[2]

Sažetak

Polazeći od činjenice da bez snažnih napora usmjerenih na očuvanje prirodnog okoliša i ublažavanje posljedica klimatskih promjena nijedan razvoj ne može biti dugoročno održiv, osnovni cilj ovog rada je istražiti odnos između ekološke učinkovitosti i postignutog gospodarskog razvoja odabranih europskih zemalja. Za ostvarenje definiranih ciljeva korištena je inovativna (dvostupanjska) istraživačka metodologija, temeljena na kombiniranoj primjeni klaster analize i jednofaktorske ANOVA-e. Klasifikacija 38 europskih zemalja u različite skupine, temeljena na vrijednostima triju ključnih komponenti Indeksa ekološke učinkovitosti (EPI) za 2023. godinu, provedena je hijerarhijskom aglomerativnom klaster analizom. Dobiveno „optimalno“ rješenje, koje se sastoji od triju klastera, nadopunjeno je rezultatima ANOVA-e radi procjene njegove statističke valjanosti te nedvojbeno potvrđuje postojanje izraženih razlika među promatranim zemljama u pogledu zabilježene ekološke učinkovitosti. Formirane skupine s dodijeljenim kategorijama (visoka, prosječna i niska ekološka učinkovitost) korištene su kao nezavisna varijabla u drugoj fazi analize, usmjerenoj na ispitivanje statističke značajnosti razlika između prosječnih vrijednosti BDP-a po stanovniku utvrđenih za tri klastera zemalja temeljenih na EPI-ju. Rezultati ANOVA-e nedvojbeno potvrđuju postojanje pozitivne i statistički značajne veze između postignutog gospodarskog razvoja i ekološke učinkovitosti temeljene na EPI-ju, za promatrane europske zemlje u 2023. godini. Dobiveni rezultati istraživanja mogu pružiti vrijedne uvide donositeljima politika održivosti te doprinijeti boljem razumijevanju prirode odnosa između gospodarskih i ekoloških pokazatelja.

Ključne riječi: *klaster analiza, jednofaktorska ANOVA, indeks ekološke učinkovitosti, BDP po stanovniku, europske zemlje*

JEL klasifikacija: *C12, C38, E01, O52, Q56*

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