


ANALYSIS OF ENVIRONMENTAL SUSTAINABILITY OF EUROPEAN UNION MEMBER STATES BASED ON THEIR KEY MACRO-LEVEL ENVIRONMENTAL INDICATORS

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Abstract. *Awareness of the environmental dimension of sustainable development has increased globally since the late twentieth century, with an emphasis on the integration of three pillars: economic prosperity, environmental quality, and social justice. In this context, environmental sustainability has gained considerable prominence, particularly in response to the growing demand for transparency regarding environmental sustainability-related information. This paper aims to analyse sustainability reporting practices concerning macro-level environmental indicators within European Union (EU) Member States, with the objective of assessing environmental sustainability at the macroeconomic level. The study utilises nine selected indicators from the Eurostat database, covering the period from 2021 to 2023. A cluster analysis was initially conducted to categorise EU Member States into two groups based on their environmental sustainability performance in 2021: the 'green' cluster (environmentally responsible countries) and the 'red' cluster (less environmentally responsible countries). This classification facilitated further analysis across the 2021–2023 period, including: the application of a T-test to examine differences in macro-level environmental indicators between countries in the 'green' and 'red' clusters; and b) the construction of a dependent variable for the purposes of logistic regression analysis. The logistic regression model was employed to evaluate the likelihood that specific macro-level environmental indicators influence the classification of a country into either the 'green' or 'red' cluster during the observed period. The findings suggest that increases in gas emissions, electricity production by fuel and operator, and inadequate waste treatment decrease the probability of an EU Member State being classified within the 'green' cluster, while simultaneously increasing the likelihood of classification within the 'red' cluster.*

Key words: *Greenhouse gas emissions, electricity generation, waste management, environmental sustainability, cluster analysis, logistic regression, EU Member States.*

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1. INTRODUCTION

The growing imperative for a sustainable, low-carbon economy has heightened the prominence of environmental, social, and governance (ESG) practices. Since the adoption of the Paris Agreement in 2015, corporate priorities have increasingly shifted towards the assessment of sustainability performance, with particular emphasis on environmental factors such as greenhouse gas emissions, energy consumption, and waste management. The European Union (EU) has established itself as a global leader in the promotion of sustainable development, with policies aimed at both aligning with international environmental protection objectives and harmonising environmental standards across its Member States (Quatrosi, 2022). Through these initiatives, the EU reinforces its position as a principal advocate for a sustainable and responsible interaction between human society and the natural environment (European Commission, DG for Energy, 2020). In accordance with its sustainability goals, EU Member States have committed to achieving net-zero greenhouse gas emissions by 2050.

In an effort to reduce greenhouse gas emissions, the EU has implemented a range of measures, most notably the EU 2020 Climate and Energy Package and the EU Emissions Trading System (EU ETS). These mechanisms establish a cap on total emissions within the EU, gradually reducing permitted quotas while promoting innovation in low-carbon technologies. As one of the largest contributors to emissions, the energy sector plays a pivotal role in the transition to renewable energy sources and the enhancement of energy efficiency. According to Eurostat, the energy sector is responsible for more than 75% of total greenhouse gas emissions in the EU, underscoring its critical significance in climate policy (Eurostat, 2023). Simultaneously, the development and deployment of renewable energy sources possess the potential to stimulate broader social and economic progress. Gases such as *carbon dioxide*, *methane* and *nitrous oxide* occur naturally in the Earth's atmosphere; however, their excessive emission due to human activity contributes significantly to the intensification of the greenhouse effect and global warming. These gases, collectively referred to as greenhouse gases (GHGs), pose a formidable challenge to the attainment of climate neutrality, necessitating rigorous monitoring and reporting as integral components of sustainable development policy. In addition to emissions and energy, waste management constitutes another key aspect of environmental sustainability. Inadequate handling of industrial and municipal waste results in soil, water, and air pollution, as well as the emission of gases such as methane from landfills. The EU's strategies for the circular economy and the European Green Deal place strong emphasis on waste prevention, recycling, and the reuse of resources in order to reduce environmental pressure and improve efficiency. The integration of waste-related indicators into the assessment of countries' environmental sustainability facilitates a more comprehensive evaluation of performance and supports the identification of resource management challenges.

The analysis of EU Member States through the lens of environmental indicators is particularly significant, not only due to their leading role in promoting policies and technologies aimed at emissions reduction, but also owing to their well-established regulatory frameworks and environmental sustainability standards. Nevertheless, these systems continue to encounter challenges in fully addressing the complexity of environmental issues. According to Eurostat data (2023), greenhouse gas emissions in the EU are projected to decline by 80% to 90% by 2050.

This study pursues a dual objective. Firstly, it aims to examine the scope of regulatory frameworks designed to promote environmentally sustainable development across EU Member States. Secondly, it undertakes an empirical investigation of environmental indicator reporting

practices across these countries, with the objective of assessing environmental sustainability at the macroeconomic level and identifying key factors that influence responsible environmental stewardship. In light of the growing significance of environmental sustainability, the study utilises nine indicators encompassing emissions, energy, and waste-related dimensions. To conduct the analysis, the following methods were applied: a) cluster analysis, used to categorise countries into two clusters – 'green' (EU Member States exhibiting stronger macro-level environmental indicators) and 'red' (countries with weaker indicators), based on their level of environmental sustainability as measured by macro-level environmental indicators; b) a T-test, applied to determine whether statistically significant differences exist between EU Member States classified in the 'green' and 'red' clusters according to macro-level environmental indicators; and c) logistic regression, used to examine how changes in selected variables influence the probability of a country belonging to the 'green' or 'red' cluster.

In line with the research objectives, this paper begins with a theoretical overview of sustainable development regulations, followed by a review of previous studies examining the factors that influence environmental sustainability. This is subsequently complemented by a detailed description of the methodology and a comprehensive discussion of the research findings, with particular emphasis on potential opportunities for future research.

2. LITERATURE REVIEW

The formulation of guidelines for non-financial reporting and the modernisation of the Fourth and Seventh Accounting Directives began in 2010, when the Directorate-General for the Internal Market and Services of the European Commission (EC) launched consultations with stakeholders regarding the EU's existing framework for non-financial information disclosure. Sustainability reporting is important because companies present their reports to stakeholders and take responsibility for their actions (Stojanović-Blab & Blab, 2024). This initiative was prompted by the growing trend in corporate social responsibility reporting, which varied across Member States. The first outcome of this process was the adoption of Directive 2013/34/EU, which replaced the previous Fourth and Seventh Directives. This new directive consolidated earlier regulations and aligned them with contemporary requirements; however, it did not result in substantial progress in the area of non-financial reporting – thereby highlighting the need for further amendment the following year through Directive 2014/95/EU (Non-Financial Reporting Directive – NFRD). The implementation of these guidelines commenced on 1 January 2018. The NFRD marked a significant shift in corporate reporting practices across EU Member States, as non-financial reporting – previously voluntary – became subject to legally binding obligations for the first time. However, the NFRD constituted a political compromise, reflecting divergent positions among the European Commission, the European Parliament, and the Council. This divergence led to considerable flexibility in both the application and interpretation of the regulations (Lanfermann & Baumüller, 2022). Consequently, companies are permitted to select from a range of non-financial reporting frameworks, thereby limiting comparability, standardisation, and the formulation of clear, prescriptive guidelines (Coenberg et al., 2024).

In April 2021, following a review of the provisions on non-financial reporting, the European Commission (EC) published a proposal for a new directive – the Corporate Sustainability Reporting Directive (CSRD) 2022/2064. The revised directive aims to improve the consistency, comparability, and transparency of non-financial information

disclosed by companies within the EU. Fundamentally, CSRD 2022/2064 supplements and builds upon the existing NFRD. The CSRD has led to an *expansion of scope – covering approximately 50,000 companies – introducing standardised reporting, mandatory assurance, the integration of sustainability and financial reporting, and digitalisation of reporting*. In 2022, the International Sustainability Standards Board (ISSB) issued drafts of two standards - ED IFRS S1, concerning the disclosure of sustainability information, and ED IFRS S2, focusing on climate-related disclosures. These standards were formally adopted and came into effect on 1 January 2024, titled IFRS S1 *General Requirements for Disclosure of Sustainability-related Financial Information* and IFRS S2 *Climate-related Disclosures*.

Simultaneously, the EC commenced work on the European Sustainability Reporting Standards (ESRS), designed to promote the standardisation and comparability of sustainability-related information. Companies required to comply with the CSRD will also be obliged to apply the ESRS. The European Financial Reporting Advisory Group (EFRAG) was appointed as the EC's technical adviser for the development of the ESRS. In April 2022, EFRAG published a draft of twelve ESRS, and the first set of standards was adopted in June 2023, applying to the 2024 reporting year, with reports to be published in 2025. The second set was adopted in June 2024 and applies to the 2025 reporting year, with reports to be published in 2026. The European standards are based on four reporting areas: corporate reporting, strategy, impacts, risk and opportunities management, and metrics and targets. They address three core thematic areas: *environmental protection, social responsibility and corporate governance*, and are structured across three levels: *sector-agnostic, sector-specific and entity-specific standards*. Following the adoption of the European standards in June 2024, the Corporate Sustainability Due Diligence Directive (CSDDD 2024/1760) was adopted.

In February 2025, the EC introduced a new proposal to simplify EU sustainability regulations - referred to as the Omnibus (COM (2025) 81 and 80). The proposal seeks to reduce the administrative burden associated with reporting and ease obligations for small and medium-sized enterprises (SMEs). The amendments proposed by the EC (European Commission, 2025a, 2025b) focus on alleviating administrative load and ensuring greater proportionality in sustainability reporting requirements. Approximately 80% of companies will be exempt from the obligations under CSRD 2022/2064, which will henceforth apply exclusively to large enterprises deemed to have a significant impact on society and the environment. These requirements will not be automatically extended to SMEs within the value chain. Furthermore, the Omnibus proposal recommends postponing the reporting start date until 2028 for companies currently subject to CSRD 2022/2064 and originally scheduled to commence reporting in 2026 or 2027. The Omnibus proposal introduces a financial materiality threshold for reporting under the EU Taxonomy, and simplifies the reporting format by 70%. Additionally, the criteria for pollution prevention related to the use of chemical substances – applicable across all economic sectors within the EU Taxonomy - have been simplified. The Omnibus also adjusts the green asset ratio, a key performance indicator for banks based on the EU Taxonomy.

The adoption of the CSDDD 1760 in 2024, alongside the EC's proposal to simplify sustainability rules (the Omnibus), represents a significant advance in regulating accountability for adverse impacts on human rights and the environment. However, by raising the applicability threshold to companies employing more than 1,000 individuals and generating an annual turnover exceeding €450 million, a substantial number of companies have been exempted from the obligation to disclose sustainability-related information. This development has, therefore, reduced the potential of the CSDDD to cover a broader segment of the market and supply chain.

The exemption of medium-sized enterprises combined with an exclusive focus on the largest corporations, may be perceived as a regression in the pursuit of transparency, sustainability, and corporate accountability. Such relaxation of disclosure obligations is particularly concerning in light of the severity of current environmental challenges.

Environmental issues represent one of the principal global challenges of contemporary society, owing to their profound impact not only on the environment but also on overall economic flows and stability. Climate change, driven by the excessive emission of greenhouse gases – particularly carbon dioxide (CO₂) – is increasingly evident and is widely acknowledged as one of the most pressing challenges of the twenty-first century (Dam et al., 2024). Industrial activity and fossil fuel based energy consumption are the primary sources of CO₂ emissions, rendering them a central concern for policymakers at the global level (Allan et al., 2023; Dhakal et al., 2022).

The reduction of greenhouse gas emissions, while maintaining economic growth, has been recognised as an essential step towards mitigating the adverse effects of climate change (Dong et al., 2021). In response to these challenges, over 130 countries globally have set goals to achieve carbon neutrality, with the European Union, through the Green Deal, setting an ambitious target to achieve net-zero CO₂ emissions by 2050 (Pata et al., 2024). Simultaneously, international frameworks such as the Paris Agreement and the 2030 Agenda highlight the urgency of transitioning to sustainable energy sources.

The largest emitters of CO₂ – namely, China, the United States, and India – account for the majority of global emissions (European Commission, 2023). This further emphasises the need for coordinated action and the monitoring of ecological indicators, which play a critical role in identifying and implementing effective strategies – ranging from regulatory measures to the promotion of climate-friendly technologies (Abbas et al., 2024).

Given that policymakers in economics and development require a quantitative foundation for designing effective and targeted measures at the macro level, various indicators may be employed to represent key performance metrics of a country. As Stefko et al. (2018) observe, at the macroeconomic level, indices serve as indicators of national-level performance and assist governments in addressing critical challenges and implementing strategies for sustainable economic development. Accordingly, the evaluation of countries through international indices is gaining increasing significance in both research and practical frameworks. Particular emphasis has been placed on investment in research and the development of innovations in clean energy, alongside the promotion of renewable energy sources as instruments for achieving a sustainable future (Raihan, 2023; Jiang et al., 2024). In this context, it is essential to analyse indicators such as CO₂ emissions, energy efficiency, and waste in order to evaluate the effectiveness of national and international environmental protection policies.

A review of the literature indicates that numerous authors have addressed ecological issues (Llorca & Rodriguez-Alvarez, 2024; Obobisa & Ahakwa, 2024; Fida & Saeed, 2023; López-Portillo et al., 2021; Dogan et al., 2013). Włodarczyk et al. (2021), in their study, examined the relationship between sustainable development and renewable energy sources in EU Member States. Applying cluster analysis on a 2019 dataset, Włodarczyk and colleagues focused on energy-related indicators, including the share of renewables in energy consumption, dependence on energy imports, and CO₂ emissions. Their findings identified five clusters of countries exhibiting varying levels of sustainability and use of renewable energy sources. Similarly, Strielkowski et al. (2024) developed a system of indicators to monitor the sustainable transformation of the energy sector in accordance with the objectives of the Paris Agreement. The authors employed cluster and discriminant

analysis to investigate decarbonisation and climate change mitigation. The key indicators identified for the formulation of sustainability strategies in European countries included energy efficiency, renewable energy generation capacity, and waste management. These findings offer guidelines for improving sustainable development policies within the energy sector. López-Portillo et al. (2021) studied waste treatment patterns across EU Member States, with a focus on recycling, composting, and energy recovery. Employing cluster analysis and the Kruskal-Wallis test, the EU Member States were classified into three clusters based on GDP per capita, research and development expenditure, resource productivity, and length of EU membership. The objective was to determine significant differences in waste management practices and identify the factors influencing them.

The existing literature reflects considerable progress in analysing the impact of individual indicators – such as CO₂ emissions, energy efficiency, renewable energy use, and waste treatment – on the sustainable development of EU Member States. Research has predominantly focused on separate areas – air, energy, or waste – using cluster analysis methods to identify behavioural patterns among countries. However, despite numerous contributions to the field of sustainable development, no study to date has adopted an integrated approach encompassing all three groups of macro-level environmental indicators – air, energy, and waste – over time. Furthermore, no study has analysed how changes in gas emissions, electricity production by operator and fuel type, and waste influence the likelihood of a country belonging to the 'green' cluster (EU Member States with superior macro-level environmental indicators) or the 'red' cluster (EU Member States with inferior macro-level environmental indicators).

3. SAMPLE DESCRIPTION AND RESEARCH METHODOLOGY

This study investigates the reporting practices of macro-level environmental indicators (air pollutants and greenhouse gases, energy and waste) across EU Member States, using data from the Eurostat database. Given that increases in environmental indicator values are associated with a country being placed in the 'red' cluster, this research will address the following questions:

Can EU Member States be categorised into homogeneous clusters based on macro-level environmental indicators related to air, energy, and waste – specifically, a 'green' cluster (environmentally more advanced countries) and a 'red' cluster (environmentally less advanced countries)?

Can distinct differences in the reporting of macro-level environmental indicators among EU Member States be identified according to the derived clusters?

Accordingly, this research aims to examine the differences in the development of environmental sustainability reporting practices at the macroeconomic level in EU Member States during the period 2021–2023. In line with the research objective, the following hypotheses are proposed:

H1: Key macro-level environmental indicators from 2021 allow for the classification of EU Member States into a 'green' cluster (environmentally responsible countries) and a 'red' cluster (less environmentally responsible countries).

H2: There is a significant difference between EU Member States classified into the 'green' and 'red' clusters based on key macro-level environmental indicators for the period 2021–2023.

H3: An increase in macro-level environmental indicators (gas emissions, electricity production by fuel type and operator, and waste treatment) decreases the likelihood of an

EU Member State being classified within the 'green' cluster, while increasing the likelihood of its classification in the 'red' cluster.

To examine the stated hypotheses, three methods were employed:

- a) Cluster analysis – This method is employed to test the first hypothesis and enables the grouping of EU Member States into 'green' and 'red' clusters. Based on the resulting clusters, a dependent variable will be created for the application of logistic regression. The dependent variable is binary in nature (1 – 'green' cluster; 0 – 'red' cluster).
- b) T-test – This method is used to test the second hypothesis, which examines whether there is a statistically significant difference in the mean values of macro-level environmental indicators between EU Member States grouped into the 'green' and 'red' clusters. This analysis provides insight into the existence of differences between the clusters and further supports the validity of the grouping, as well as the application of the logistic regression method.
- c) Logistic regression – This method is used to test the third hypothesis. The results indicate the extent to which the selected macro-level environmental indicators can predict the likelihood of a country belonging to the 'green' or 'red' cluster.

The research is based on secondary data obtained from the Eurostat database for the period 2021–2023 (Eurostat, 2025), covering 27 EU Member States. Nine indicators were selected to represent air quality, electricity production by fuel type and operator, and waste management. The selected indicators are presented in Table 1.

Table 1 Key indicators included in the research

Acronym	Data Sources	Group indicators	Name of variable	Measurement Unit
E1	Eurostat	Airpollutants and greenhouse gases	Methane	Tonne
E2	Eurostat		Carbondioxide	Tonne
E3	Eurostat		Nitrousoxide	Tonne
E4	Eurostat	Energy	Supply, transformation and consumption of solid fossil fuels	Thousand tonnes
E5	Eurostat		Gross and net production of electricity and derived heat by type of plant and operator	Gigawatt-hour
E6	Eurostat		Electricity production capacities by main fuel groups and operator	Megawatt
E7	Eurostat		Metal –ores	Thousandtonne
E8	Eurostat	Waste	Non-metallic minerals	Thousandtonne
E9	Eurostat		Fossil energy materials/carriers	Thousandtonne

Source: Author's creation based on the compiled database

Cluster analysis enables the grouping of observed units into clusters or classes based on similarity, while simultaneously distinguishing them from other groups. Various algorithms exist for cluster analysis; however, two approaches have emerged as the most prominent: hierarchical and non-hierarchical. The final result of hierarchical cluster analysis is a dendrogram – a tree-like graphical representation of linkages. The aim of hierarchical analysis is to display the similarity structure of entities without necessarily producing distinct clusters (Newbold et al., 2010). The non-hierarchical approach, by contrast, offers greater flexibility, allowing units to be reassigned between groups over multiple stages of the analysis. A common procedure includes arbitrarily determining

initial grouping points. Based on these points, average values are calculated during multiple stages of the analysis. Units are then moved to the group whose centre they are closest to. This process is repeated until a stable assignment of units to a predefined number of clusters is achieved. Thus, the main goal of non-hierarchical cluster analysis is to classify observed entities into an arbitrary or predefined number of clusters based on the observed characteristics (Newbold et al., 2010) – the approach adopted in this study. For the grouping of countries, the non-hierarchical classification method will be employed.

Before conducting cluster analysis, it is necessary to determine whether a high degree of correlation exists among the observed variables. If a high level of correlation between the indicators is present, this justifies the application of normalisation and the careful selection of an appropriate methodological approach for cluster formation

Table 2 Pearson's correlation coefficients for selected environmental sustainability variables

	E1	E2	E3	E4	E5	E6	E7	E8	E9
E1	1.0000								
E2	0.8504 (0.0000)	1.0000							
E3	0.9521 (0.0000)	0.8966 (0.0000)	1.0000						
E4	0.5374 (0.0000)	0.8475 (0.0000)	0.6634 (0.0000)	1.0000					
E5	0.8754 (0.0000)	0.8903 (0.0000)	0.8997 (0.0000)	0.6030 (0.0000)	1.0000				
E6	0.8297 (0.0000)	0.9145 (0.0000)	0.8287 (0.0000)	0.6617 (0.0000)	0.9625 (0.0000)	1.0000			
E7	0.8463 (0.0000)	0.8516 (0.0000)	0.7938 (0.0000)	0.5229 (0.0000)	0.8383 (0.0000)	0.8538 (0.0000)	1.0000		
E8	0.7224 (0.0000)	0.7735 (0.0000)	0.8195 (0.0000)	0.6717 (0.0000)	0.8307 (0.0000)	0.7961 (0.0000)	0.6305 (0.0000)	1.0000	
E9	0.8632 (0.0000)	0.9398 (0.0000)	0.8982 (0.0000)	0.6794 (0.0000)	0.9574 (0.0000)	0.9524 (0.0000)	0.8940 (0.0000)	0.8167 (0.0000)	1.0000

Source: Author's calculations in SPSS v.26

The Pearson correlation coefficients obtained for the selected indicators reflecting the environmental sustainability of EU Member States indicate a high level of intercorrelation (over 0.9). The set of selected indicators undergoes the following phases: data normalisation and determination of the optimal number of clusters. Data normalisation is conducted to ensure appropriate data processing during the analysis, meaning that all indicators will have an equal impact on cluster formation, as the selected indicators are expressed in different measurement units. In other words, the variables are brought to the same scale. Normalisation was performed using the Z-score method, standardises variables to enable comparison in terms of their influence on the analysis, regardless of their original measurement scale (Hair et al., 2010). This method ensures that each variable in the analysis has a mean of zero and a standard deviation of one. It indicates the distance of a particular value from the mean, expressed in standard deviation units. The Z-score transformation method is expressed by the following formula:

$$x' = \frac{x - \mu}{\sigma} \quad (1)$$

Where:

x – original value of the variable

μ – mean value of the variable

σ – standard deviation of the variable

x' – standardised value (Z-score)

Standardisation ensures that all indicators contribute equally to the analysis by eliminating the influence of differing measurement scales. This approach enhances data comparability and contributes to the reliability of the cluster analysis results, as it prevents certain indicators from dominating others solely due to their numerical range. Meanwhile, logistic regression is used to examine the relationship between multiple indicators (independent variables in the model) and a categorical dependent variable, representing cluster membership in this study in one of two clusters (1 – 'green'; 0 – 'red'). Logistic regression is employed to estimate the probability that a given unit of observation (i.e., an EU Member State) belongs to either the 'green' or the 'red' cluster, based on the selected set of indicators.

4. RESEARCH RESULTS

Using non-hierarchical cluster analysis, which enables the grouping of countries into a predetermined number of clusters, the EU Member States were categorised into a 'green' and a 'red' cluster. The results of the K-means cluster analysis for 2021 indicate the following:

- The first cluster ('green' cluster) includes: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Portugal, Romania, Slovakia, Slovenia, and Sweden.
- The second cluster ('red' cluster) includes: France, Germany, Italy, the Netherlands, Poland, and Spain.

The visualisation of the cluster analysis results on a geographical map offers a clear representation of the spatial distribution of EU Member States based on the identified clusters. This type of visual display facilitates the identification of regional patterns and variations in the level of environmental sustainability among the selected countries. In the map (Fig. 1), the clusters are represented using two colours: green for environmentally sustainable countries, and red for countries with relatively lower environmental performance.

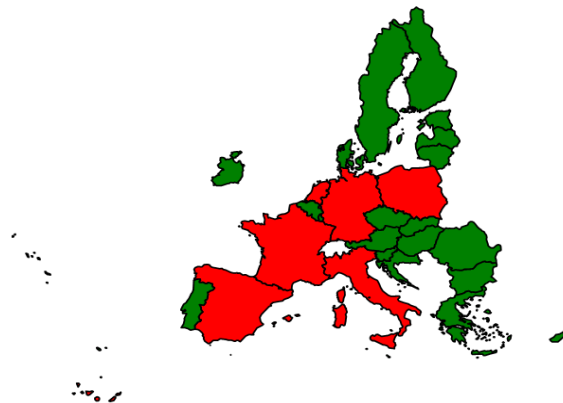


Fig. 1 Cluster distribution: geographical representation – 'green' and 'red' clusters

Source: Author's creation using STATA 13

Following the classification of countries into the 'green' and 'red' clusters, an independent samples T-test was conducted to assess whether there was a statistically significant difference in the mean values of the independent variables between the two clusters (significance level set at $p < 0.05$). The results of the T-test are presented in Table 3.

Table 3 T-test results for key macro-level environmental indicators in EU Member States classified into 'green' and 'red' clusters during the period 2021 to 2023.

2021					
Variable	Cluster	Mean	Difference in mean value between clusters*	Std. Dev.	$Pr(T > t)$
E1	“Red”	1,447,799	6.15	182,680	0.001
	“Green”	235,602		47,198	
E3	“Red”	63,786	5.46	10,983	0.001
	“Green”	11,681		1,994	
E5	“Red”	335,604	7.80	195,125	0.001
	“Green”	43,000		41,582	
E6	“Red”	106,100	8.97	73,042	0.001
	“Green”	11,828		10,277	
E8	“Red”	113,239	3.99	32,979	0.002
	“Green”	28,367		9,095	
2022					
Variable	Cluster	Mean	Difference in mean value between clusters*	Std. Dev.	$Pr(T > t)$
E1	“Red”	1,418,105	6.08	180,724	0.001
	“Green”	233,119		47,117	
E3	“Red”	61,177	5.53	10,748	0.001
	“Green”	11,071		1,829	
E5	“Red”	322,016	7.59	71,247	0.001
	“Green”	42,453		9,040	
E6	“Red”	109,147	8.86	30,195	0.001
	“Green”	12,323		2,329	
E8	“Red”	116,771	4.13	32,929	0.001
	“Green”	28,296		9,025	
2023					
Variable	Cluster	Mean	Difference in mean value between clusters*	Std. dev	$Pr(T > t)$
E1	“Red”	1,454,445	5.86	183,822	0.001
	“Green”	248,340		50,158	
E3	“Red”	56,598	5.72	9,609	0.001
	“Green”	9,903		1,643	
E5	“Red”	312,805	7.53	69,711	0.001
	“Green”	41,558		8,638	
E6	“Red”	114,344	8.92	32,085	0.001
	“Green”	12,818		2,442	
E8	“Red”	116,278	4.03	33,846	0.001
	“Green”	28,826		9,004	

Note: The 'red' cluster comprises six countries, while the 'green' cluster comprises 21 countries.

*The difference in average values between clusters is calculated as the ratio of the average value of the 'red' cluster to that of the 'green' cluster.

The results of the T-test for *methane emissions* indicate that there is a statistically significant difference between the 'green' and 'red' clusters during the period from 2021 to 2023 ($p < 0.001$). Countries in the 'green' cluster recorded, on average, approximately six times lower *methane emissions* compared to those in the 'red' cluster throughout the analysed period (2021–2023). These observed differences remain consistently significant, confirming methane's potential as a predictor in logistic regression for distinguishing differences in countries' environmental efficiency. Similarly, the T-test results for *nitrous oxide emissions* reveal significant differences between the 'green' and 'red' clusters across all three years ($p < 0.001$), with countries in the 'green' cluster exhibiting approximately 5.6 times lower nitrous oxide emissions on average.

The difference in the value of *gross and net production of electricity and derived heat by type of plant and operator* between the 'green' and 'red' clusters is 7.5-fold. This indicates that EU Member States in the 'green' cluster produce 7.5 times less energy compared to those in the 'red' cluster. Additionally, countries in the 'green' cluster have, on average, approximately nine times lower *electricity production capacities by main fuel groups and operator* compared to EU Member States in the 'red' cluster.

Non-metallic mineral production is, on average, about 4.5 times lower in countries belonging to the 'green' cluster compared to those in the 'red' cluster during the period from 2021 to 2023.

By demonstrating a statistically significant difference between the clusters, this analysis supports the relevance of examining the impact of macroeconomic environmental indicators on the environmental sustainability of EU Member States. Furthermore, the use of cluster analysis enabled the creation of a dependent variable for logistic regression. Logistic regression was performed using five models for each year. It should be noted that each model was run for individual indicators due to the potential problem of multicollinearity, as the correlation between E1 and E3; E2 and E6; E2 and E9; E5 and E6; E5 and E9; and E6 and E9 exceeds 0.9 (Table 2). This approach also allows for the individual measurement of the effects of the selected macro-level environmental indicators. The results of the logistic regression are presented in Table 4.

In the period from 2021 to 2023, all analysed indicators demonstrate a statistically significant effect on the probability of belonging to the 'green' cluster ($p < 0.05$). If the *odds ratio* is less than 1, this indicates an inverse relationship between the independent and dependent variables; that is, an increase in the values of macroeconomic environmental indicators decreases the probability that a country belongs to the 'green' cluster, or conversely, increases the probability of belonging to the 'red' cluster.

In the first logistic regression model for the period 2021 to 2023, the impact of *methane emissions* on the probability of a country belonging to the 'green' cluster was examined. The results indicate that *methane emissions* across all three years contributed to a decrease in the probability of an EU Member State being classified within the 'green' cluster. The *odds ratio* for *methane* increased over the analysed period (from 0.0165503 in 2021 to 0.0289059 in 2023), but the value remained below one, indicating that as *methane emissions* rise, the likelihood of a country being in the 'green' cluster decreases. In the second model, the relationship between *nitrous oxide emissions* and the probability of cluster membership was examined. *Nitrous oxide emissions* also contributed to a decreased probability of a country being classified in the 'green' cluster during the period under review (the odds ratio remained below one – from 0.0071743 in 2021 to 0.0024262 in 2023).

Table 4 Logistic regression results

Variable	2021		
	Coef.	Prob> chi2	Oddsratio
E1	-4.101351 (0.051)	0.001	0.0165503
E3	-4.937251 (0.039)	0.001	0.0071743
E5	-6.321277 (0.041)	0.001	0.0017976
E6	-7.964452 (0.050)	0.001	0.0003476
E8	-1.446039 0.019	0.004	0.2355013
Variable	2022		
	Coef.	Prob> chi2	Oddsratio
E1	-3.995916 (0.044)	0.001	0.0183906
E3	-5.530081 (0.044)	0.001	0.0039657
E5	-5.790738 (0.040)	0.001	0.0030557
E6	-8.011977 (0.055)	0.001	0.0003315
E8	-1.495012 (0.018)	0.003	0.2242459
Variable	2023		
	Coef.	Prob> chi2	Oddsratio
E1	-3.54371 (0.023)	0.001	0.0289059
E3	-6.021428 (0.057)	0.001	0.0024262
E5	-6.18185 (0.044)	0.001	0.0020666
E6	-8.050758 (0.055)	0.001	0.0003189
E8	-1.495577 (0.019)	0.003	0.224119

Source: Authors calculating using STATA 13

For gross and net production of electricity and derived heat by type of plant and operator, as well as electricity production capacities by main fuel groups and operator, it was also observed during the period 2021–2023 that the odds ratio remained below 1. This suggests that the expansion of industrial capacities and electricity production constitutes a barrier to belonging to the more environmentally responsible group of countries, as confirmed in the third and fourth models.

The odds ratio value for non-metallic minerals is also less than 1, indicating that an increase in this indicator reduces the probability of a country being classified within the 'green' cluster, as shown in the fifth logistic regression model.

By applying cluster analysis, EU Member States were classified into a 'green' cluster (comprising 21 countries) and a 'red' cluster (comprising 6 countries), based on their level of environmental sustainability, which was measured using macro-level environmental indicators in 2021. This confirmed the first hypothesis (H1). Additionally, cluster analysis served as the foundation for testing H2, which was evaluated using a T-test, and H3, which was examined through logistic regression. The results of the T-test confirmed a statistically significant difference between the 'green' and 'red' clusters into which EU Member States were grouped based on macroeconomic indicators during the period 2021–2023, thereby confirming the second hypothesis (H2). The application of logistic regression confirmed the third hypothesis (H3), namely, that an increase in gas emissions, electricity production by fuel type and operator, and waste reduces the probability of an EU Member State belonging to the 'green' cluster, while increasing the probability that the country belongs to the 'red' cluster.

5. CONCLUSION

The research focused on three principal areas of environmental protection: gas emissions, energy management, and waste treatment. Their combined impact on the environmental sustainability of EU Member States at the macroeconomic level was analysed over a three-year period, from 2021 to 2023. The use of cluster analysis enabled the classification of EU Member States into two groups: the 'green' cluster (comprising 21 countries) and the 'red' cluster (comprising six countries). The results of the T-test demonstrated a statistically significant difference between the 'green' and 'red' clusters, thereby justifying the application of logistic regression. Logistic regression was employed to examine the relationship between the selected macro-level environmental indicators and the probability of a country belonging to either the 'green' or 'red' cluster. Based on the results of the logistic regression, it may be concluded that an increase in gas emissions, electricity production, and waste generation reduces the likelihood that an EU Member State belongs to the 'green' cluster, while increasing the likelihood of its membership in the 'red' cluster.

This paper contributes to a better understanding of the environmental determinants of sustainability at the macro level among EU Member States. The analysis identified three key areas: greenhouse gas emissions, electricity production, and waste treatment as significant factors influencing responsible environmental stewardship. These variables were found to meaningfully affect a country's likelihood of being classified within the environmentally sustainable ("green") cluster. Their identification provides a clearer picture of the environmental dimensions that distinguish more sustainable countries from those lagging behind. The findings highlight the importance of sustained efforts in emissions reduction, increasing energy efficiency and the share of renewables, as well as advancing waste management systems as essential components of responsible environmental governance.

The limitations of this research relate to the availability and quality of data, the restricted time frame of the analysis, and the limitation of logistic regression in capturing potential nonlinearities or interactions between variables.

Future research could expand the analysis by incorporating additional sustainability indicators, employing more advanced econometric methods, and comparing findings with countries outside the EU – particularly the Republic of Serbia. It would also be beneficial to assess Serbia's position – specifically, whether, based on macro-level environmental

indicators, it aligns more closely with the 'green' or 'red' cluster, and the extent to which these indicators determine its likelihood of belonging to either group. Such analysis would provide a valuable basis for formulating Serbia's national sustainable development policy in accordance with EU standards.

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ANALIZA EKOLOŠKE ODRŽIVOSTI ZEMALJA EU NA OSNOVU NJIHOVIH KLJUČNIH EKOLOŠKIH INDIKATORA NA MAKRO NIVOU

Svest o ekološkoj dimenziji održivog razvoja u globalnim okvirima počinje da raste krajem 20. veka, sa tendencijom da se izgradi na tri stuba: ekonomskom prosperitetu, kvalitetu životne sredine i socijalnoj pravdi. Pitanja ekološke održivosti sve više dobijaju na značaju imajući u vidu porast zahteva za obelodanjivanjem informacija o ekološkoj održivosti. Cilj rada je analiza praksi izveštavanja o ključnim ekološkim indikatorima na makro nivou zemalja Evropske Unije (EU) radi procene njihove ekološke održivosti na makroekonomskom nivou korišćenjem devet odabranih indikatora iz baze Eurostat za period od 2021. do 2023. godine. U tu svrhu je primenjena najpre klaster analiza za grupisanje zemalja EU u dva klastera prema stepenu ekološke održivosti merenom ekološkim indikatorima na makro nivou u 2021. godini - „zeleni“ (grupa ekološki odgovornih zemalja EU) i „crveni“ (grupa manje ekološki odgovornih zemalja). Ova klaster analiza je u periodu od 2021. do 2023. godine omogućila: a) primenu T-testa radi utvrđivanja razlike u ekološkim indikatorima na makro nivou između zemalja EU koje pripadaju „zelenom“ i „crvenom“ klasteru; b) kreiranje zavisne varijable za potrebe logističke regresije. Metoda logističke regresije je omogućila analizu verovatnoće uticaja ekoloških indikatora na makro nivou na pripadnost zemalja EU „zelenom“ ili „crvenom“ klasteru u periodu od 2021. do 2023. godine. Na osnovu dobijenih rezultata logističke regresije može se zaključiti da rast vrednosti emisije gasova, proizvodnje električne energije prema gorivu i distributeru i neadekvatnog tretmana otpada utiče na smanjenje verovatnoće da zemlja EU pripada „zelenom“ klasteru, dok njihov rast povećava verovatnoću da zemlja EU pripadne „crvenom“ klasteru.

Ključne reči: emisija gasova, proizvodnja električne energije, otpad, ekološka održivost, klaster analiza, logistička regresija, zemlje EU