European Journal of Sustainable Development (2025), **14**, 3, 915-927 ISSN: 2239-5938
Doi: 10.14207/ejsd.2025.v14n3p915

Measuring the Sustainability Performance of EU Countries through a Composite Multidimensional Index

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ABSTRACT:
This paper proposes a sustainability index that captures the economic, environmental, and social performance of EU countries. Using a set of standardized indicators grouped into three dimensions, we construct sub-indices for each pillar and aggregate them into a composite score. The index reflects the multidimensional nature of sustainability and enables cross-country comparison. The main objective of this paper is to construct a composite sustainability index for EU countries and analyze their multidimensional performance using PCA and cluster analysis. Data is drawn from Eurostat and other relevant sources, covering recent years. To ensure comparability and robustness, we apply normalization techniques and explore weighting schemes through principal component analysis. The final index is analyzed spatially and statistically, identifying sustainability leaders and laggards within the EU. This approach contributes to the understanding of national sustainability dynamics and supports data-driven policy recommendations aimed at enhancing balanced progress across key domains.

Key words: sustainability, sustainable development, SDG indicators, composite index, country clustering.

1. Introduction

Sustainability plays a crucial role in global well-being by balancing economic development, environmental protection, and social justice. It is rooted in the recognition of limited resources and complex global challenges, serving as a foundation for societal resilience and long-term stability. A central component of this concept is the Sustainable Development Goals (SDGs), adopted by the United Nations in 2015. These 17 interconnected goals aim to tackle key issues such as poverty, health, education, gender equality, clean water access, and climate change. They provide a common platform for building a greener and fairer world, with countries integrating them into national strategies (Islam, 2025). Sustainability has become a central topic in modern society, with researchers increasingly focusing on the relationships between individuals, states, and industry. To understand the relationships between people, technology, and sustainable development goals, it is necessary to apply systemic approaches and use reliable performance indicators. In this context, multi-criteria analysis appears to be an extremely effective tool, enabling a comprehensive assessment of progress towards sustainability (D´Adamo et. al., 2025).

Current climate conditions and the increasing incidence of natural disasters pose a serious risk not only to public health but also to the stability of the global economy. As a result of these challenges, there is growing pressure on governments and businesses to implement sustainable strategies and respond to changing societal and market

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expectations. In this context, ESG (environmental, social, and governance factors) are increasingly being used as a framework for evaluating national policies in terms of their contribution to sustainable development. ESG is also an important tool in macroeconomic planning, where it supports long-term economic resilience and social balance (Yuan et. al., 2025). In recent decades, countries have increasingly struggled to align economic growth with sustainability principles. As environmental, social, and governance (ESG) factors gain importance, ESG has become a vital framework for assessing national and corporate sustainability efforts. Initially introduced in a 2004 UN report to encourage sustainable investment decisions by financial institutions, the concept has since evolved from corporate responsibility to a national policy tool. Today, ESG performance is seen as an indicator of a country's ability to achieve sustainable development - not just economically, but also in a socially and environmentally balanced manner (Ko et al., 2025).

Sustainable development is a complex process that requires systemic and integrated thinking. Theories such as the environmental Kuznets curve, which assumes an inverted U-shaped relationship between income and environmental pollution, highlight the interconnection between economic growth and environmental quality. Similarly, the concept of environmental poverty and institutional approaches emphasize the importance of integrated policies. While these approaches provide a theoretical framework, they offer only limited practical recommendations for effectively managing these complex relationships (Seelajaroen and Jitmaneeroj, 2025).

The relationship between economic growth, energy consumption, and environmental quality is strongly interlinked. Economic activity increases energy demand, often leading to environmental degradation. However, the Environmental Kuznets Curve theory suggests that beyond a certain income threshold, this trend may reverse, leading to improvements in environmental conditions (Chovancová et. al., 2024). Guo and Shahbaz (2024), discuss the environmental Kuznets curve in further detail, arguing that at the beginning of economic development, economic growth increases environmental degradation (scale effect). Later, pollution continues to increase, but at a slower pace. After reaching a turning point, the quality of the environment begins to improve (compositional effect). In the advanced stage of development, degradation is significantly reduced due to technological progress, which enables a return to a better state of the environment (technological effect).

Hasan et al., (2023) confirm the validity of the environmental Kuznets curve (EKC) in the context of industrial growth and CO_2 emissions in BRICS countries. The results suggest that sustainable development is possible through technological advances in energy, industrialization, and government intervention. The authors recommend introducing environmental taxes for fossil fuel industries and supporting green technologies through subsidies, thereby achieving a balance between growth and environmental protection. A study by Odei et al., (2025) confirms the relevance of the environmental Kuznets hypothesis in conditions of intensive research and development. The EKC turning point comes at a higher income and lower pollution level than without investment in research. The results show that technological progress can separate economic growth from environmental damage. Research and development speed up the transition to more sustainable growth, shorten the phase of environmental degradation, and support more eco-friendly economic models.

Sustainability assessment is a tool to support decision-making in policies, plans, and projects. In recent years, interest in this topic has grown significantly, particularly in the use of sustainability indicators, which provide important information for planning, monitoring, and evaluation. These indicators should reflect economic, environmental, and social aspects in a balanced way (Centrulo et al., 2025). Economic indicators are crucial for assessing economic development and policymaking. However, the relationship between them and ESG (environmental, social, and governance) performance has not yet been sufficiently explored. Some research suggests that strong ESG performance can support economic growth, particularly through efficient use of resources and better governance. This view is supported by the green growth theory, according to which ESG initiatives contribute to sustainable economic development (Qureshi et. al., 2025). A study by Leung et al. (2025) highlights that economic stability is not only a necessity for sustainable development, but also a key factor influencing ESG (environmental, social, and governance) performance. Economic crises can undermine institutions' ability to respond, reduce public funding for sustainable investments, and lead to policy decisions that prioritize short-term economic goals over long-term environmental and social commitments. These negative impacts are particularly acute in developing countries, where institutions are more vulnerable and dependence on external resources is higher. However, countries' reactions to crises vary, and not all countries face these challenges in the same way. Businesses and investors are increasingly recognizing the importance of environmental, social, and governance (ESG) indicators, which are becoming a key factor in decision-making and investment strategy development. These indicators promote long-term sustainable development and generate mutually beneficial solutions for all participants (Song et. al., 2025).

The European Union, as a complex entity comprising 27 countries with diverse cultural, economic, and environmental backgrounds, faces challenges in coordinating a unified sustainability policy. Differences in economic performance, availability of natural resources, and political priorities are also reflected in countries' performance across ESG dimensions, highlighting the importance of objective, multidimensional assessment. Several studies have already addressed the construction of composite indices at the European level. Kiselakova et al. (2020) empirically analyzed the sustainability of EU countries using a multidimensional index composed of economic, social, and environmental indicators, revealing significant differences between member states. Brodny and Tuták (2021) conducted a similar assessment in energy sustainability for the EU-27, while Guijarro and Poyatos (2022) applied target programming to calculate a sustainable development index for the EU-28, arguing for equal weights as a manifestation of equality between individual targets. The arithmetic mean as an aggregation method remains dominant, mainly due to its transparency and simplicity, which explains why it is often used in internationally recognized indices such as the Global Innovation Index, African Green Growth Index, and SDG Index.

2. Methods

The analytical part of the paper is based on panel data from European Union member states, including the EU, for the period from 2004 to 2023. The selection of variables was based on their availability, relevance to the concept of sustainability, and alignment with frameworks such as the Sustainable Development Goals (SDGs) and ESG principles. The main source of data was the Eurostat portal.

The indicators were grouped into three dimensions. The economic dimension includes employment rates (ages 20–64, %), gross domestic expenditure on research and development (euro per inhabitant), and real GDP (euro per capita). The environmental dimension consists of greenhouse gas emissions (per capita), recycling rate of municipal waste (%), and share of renewable energy in gross final energy consumption (%). The social dimension includes tertiary educational attainment (ages 25–34, %), life expectancy (years), and the at-risk-of-poverty rate (defined as 60% of the median equivalized income after social transfers (%)). Governance-related indicators were not included in the present analysis, as the study primarily follows an ESG-based framework focused on economic, environmental, and social dimensions.

Before the analysis, all variables were standardized using z-scores (centering and scaling) to eliminate the impact of different units and scales. In cases where a higher value indicated a negative phenomenon (e.g., greenhouse gas emissions or at-risk-of-poverty rate), the values were transformed so that a higher score represented a more favorable condition. Principal component analysis (PCA) was then applied to each of the three dimensions, with the first principal component interpreted as the aggregate index for that dimension. PCA allows for dimensionality reduction while preserving as much variance as possible. This ensures that the most informative patterns among variables are retained in the composite index. The resulting three sub-indices were then averaged to create an overall multidimensional index, assuming equal weight for all three dimensions. To assess the robustness of this approach, a sensitivity analysis using alternative weighting schemes was also conducted.

To complete the analysis, Spearman's correlation coefficient was used to examine the relationships between individual indicators and their contribution to the final score. To create a typology of countries, we applied hierarchical cluster analysis (Ward's method, Euclidean distance), which identified homogeneous groups of countries with similar sustainability profiles. These clusters were then compared based on the average values of the sub-indices to determine their specific characteristics and developmental disparities in terms of sustainability. The whole analytical process, including data processing and visualization, was performed in the statistical software RStudio.

3. Results

Based on the methodological approach, separate indices were compiled for each of the three dimensions of sustainability – economic, environmental and social – using the principal component (PC1) from the principal component analysis (PCA). These indices represent the relative performance of EU countries within each sustainability field. A comprehensive multidimensional index was also constructed as the average of the three sub-indices. In the next section, these results are visualized using bar graphs that illustrate the scores of individual countries within each dimension, as well as their overall scores. Before presenting the results, it should be emphasized that the concept of sustainability was approached in this analysis as a multidimensional phenomenon comprising three basic pillars. Each of these areas represents a specific dimension of EU countries' performance, and their combination provides a comprehensive view of how balanced the development of individual countries is in terms of sustainability. The resulting approach therefore does not only evaluate individual indicators, but integrates them into aggregate scores, enabling the classification of countries and identification of dominant profiles.

To combine indicators with different units and scales, we used standardization using z-scores. For each indicator, the z-score was calculated according to the form:

$$z = \frac{x - \bar{x}}{\sigma} \tag{1}$$

(x = country average, $\bar{x}$ = average of all countries, σ = standard deviation of all countries)

Principal component analysis (PCA) was applied to standardized average values of indicators for the years 2004–2023 for each dimension. The first principal component (PC1) was selected as the representative index for each dimension, as it captures the largest proportion of total variance. For the Economic dimension, PC1 explains 74.65% of the variability. The loadings are relatively balanced across the indicators: Gross domestic expenditure on research and development (0.639), Real GDP (0.574) and Employment rate (0.511). In the Environmental dimension, PC1 accounts for 52.95% of the variance. The most influential indicators are greenhouse gas emissions per capita (0.728) and the share of renewable energy in gross final energy consumption (0.565), while the recycling rate of municipal waste contributes less strongly (0.389). For the Social dimension, PC1 explains 53.96% of the total variance. The most significant contributors are Life expectancy (0.650), Tertiary educational attainment (0.512) and At-risk-of-poverty rate (0.562). PCA loadings do not represent weights in a strict sense, but rather the correlation between each original variable and the principal component. Their absolute value reflects the strength of association with the latent construct. The interpretation of each principal component was therefore based on the absolute values of the loadings, indicating how strongly each indicator is associated with the underlying sustainability dimension.

The aggregate economic sustainability index (Figure 1) calculated based on principal component analysis (PCA) of the following indicators: Employment rates, Gross domestic expenditure on research and development, and Real GDP, reveals significant differences between EU countries. The highest scores are achieved by Luxembourg (1.99), Sweden (1.99) and Denmark (1.69), followed by Finland (1.15), Germany (1.13), Netherlands (1.11) and Austria (1.10), reflecting their strong performance across all three variables. At the opposite side of spectrum are Greece (-1.19), Croatia (-1.18), Romania (-1.18), Bulgaria (-1.01), Poland (-0.97), Hungary (-0.89), Slovakia (-0.82) and Italy (-0.73), which signals economic challenges, particularly in the fields of productivity and employment. The EU average (-0.0003) is used as a reference point for comparing individual countries. Seventeen of the EU27 countries are below this average, indicating potential for improvement in economic performance.

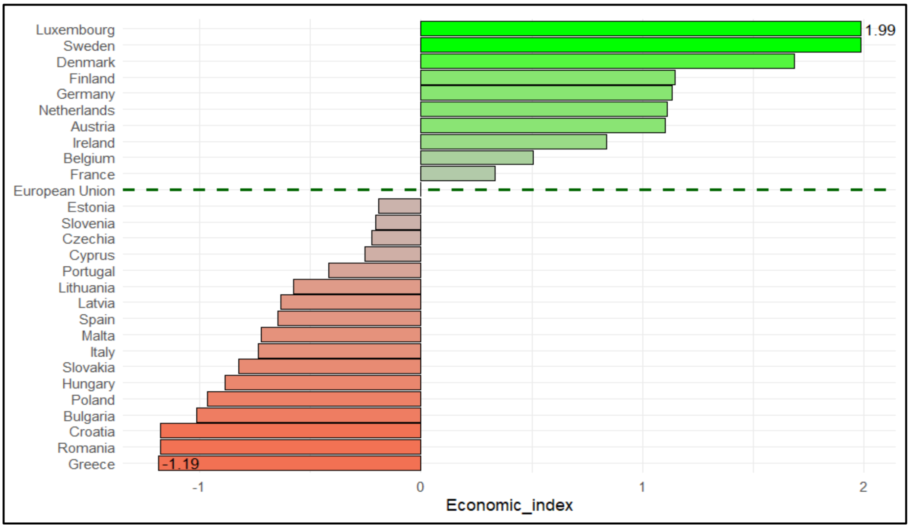

Figure 1: Economic index of EU countries (2004-2023)
Source: Own elaboration by software RStudio

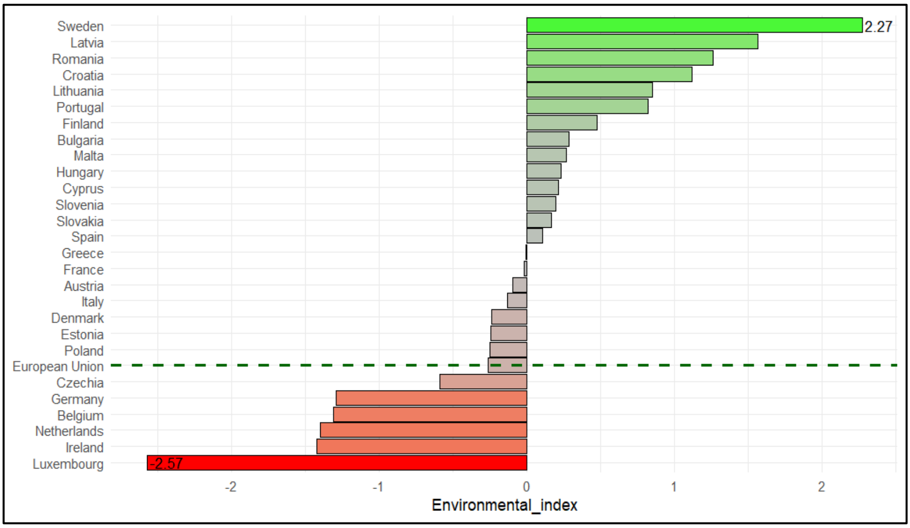

Figure 2: Environmental index of EU countries (2004-2023)
Source: Own elaboration by software RStudio

The environmental sustainability index (Figure 2) was constructed based on PCA from the indicators Greenhouse gas emissions, Recycling rate of municipal waste, and share of renewable energy in gross final energy consumption. The results demonstrate significant differences in environmental performance between EU countries. Sweden is the clear leader (2.27), followed by Latvia (1.56), Romania (1.26) and Croatia (1.12), which achieve above-average environmental scores, mainly due to their high use of renewable resources or low emissions. Lithuania (0.85), Portugal (0.82) and Finland (0.48) also scored better than average. Luxembourg (-2.57) had the worst Environmental Index score. Ireland (-1.42), the Netherlands (-1.40), Belgium (-1.3), Germany (-1.29) and the Czech

Republic (-0.59) are below the EU reference point (-0.26), which indicates a higher environmental pressure, for example in the form of higher emissions or a low share of renewable energy sources. Poland (-0.25), Estonia (-0.24) and Greece (0.006) also have negative values, but despite this, they are already ahead of the EU average.

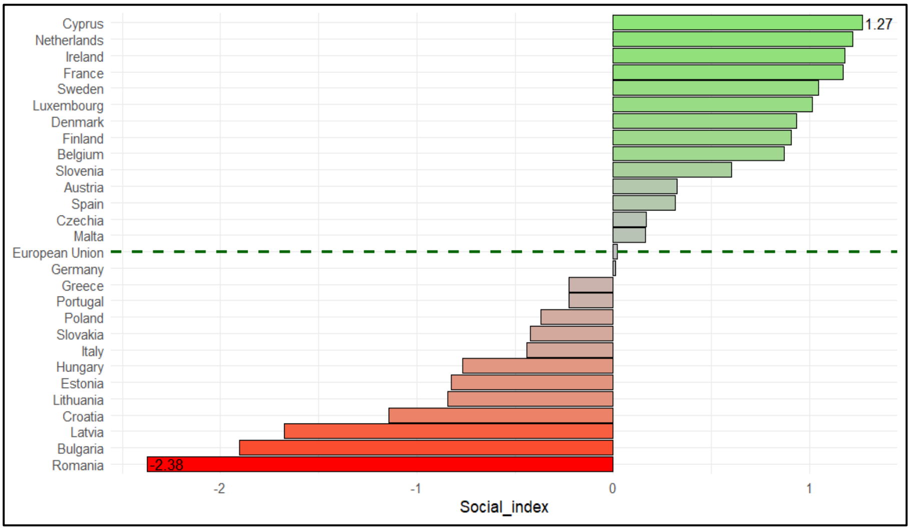

Figure 3: Social index of EU countries (2004-2023)
Source: Own elaboration by software RStudio

The social index (Figure 3) reflects aspects of quality of life, social inclusion, and access to education. The index was compiled based on PCA from the following indicators: tertiary educational attainment, life expectancy, and at-risk-of-poverty rate. The results show that Cyprus (1.27), the Netherlands (1.22), Ireland (1.18), France (1.17) and Sweden (1.05) achieve the highest scores, indicating a strong social background, a high proportion of educated young people and a lower poverty rate. On the other hand, Romania (-2.38), Bulgaria (-1.90), Latvia (-1.67), Croatia (-1.14) and Lithuania (-0.84), pointing to persistent problems in social inclusion, health status, and educational outcomes of the population. The EU average (0.02) again serves as a reference point. Approximately half of EU countries are above this average, reflecting solid social performance in several countries, particularly in Western and Northern Europe.

After extracting the first principal component (PC1) for each dimension (economic, environmental, and social), we obtained three separate sub-indices representing the performance of countries in these areas. This means that each sub-index was transformed into a Z-score, expressing how many standard deviations a country's value deviates from the mean of all countries in that dimension. As a result, all three dimensions are converted to the same scale. Subsequently, the polarity of the indices was adjusted where necessary so that higher values consistently reflect better performance. Finally, the Multidimensional Index (Figure 4) was calculated as the simple average of the three standardized sub-indices.

To assess the robustness of the composite sustainability index, a sensitivity analysis was conducted by adjusting the weighting schemes used for the three sustainability dimensions. In addition to the baseline scenario using the same weights (1/3 for each dimension), three alternative scenarios were tested, each of which prioritized one of the dimensions by assigning a weight of 0.5, while the remaining two dimensions were given weights of 0.25. The final index was recalculated for each scenario, and the countries were re-evaluated accordingly.

Table 1: Country rankings under alternative weighting scenarios of the multidimensional sustainability index

Country	Baseline	Economic	Environment	Social
Austria	5	4	6	8
Belgium	12	11	21	11
Bulgaria	28	28	28	27
Croatia	21	24	12	25
Cyprus	6	10	5	5
Czechia	18	15	20	17
Denmark	3	2	3	3
Estonia	22	20	25	23
EU	15	13	15	16
Finland	2	3	2	2
France	4	7	4	4
Germany	13	9	24	15
Greece	24	26	22	20
Hungary	25	23	19	24
Ireland	8	8	16	7
Italy	23	22	23	21
Latvia	19	19	8	26
Lithuania	17	18	10	18
Luxembourg	10	5	27	9
Malta	16	17	11	14
Netherlands	7	6	14	6
Poland	26	25	26	22
Portugal	11	14	7	13
Romania	27	27	18	28
Slovakia	20	21	17	19
Slovenia	9	12	9	10
Spain	14	16	13	12
Sweden	1	1	1	1

Source: Own elaboration by software RStudio

The results presented in Table 1 show that the ranking remains relatively stable across the four weighting scenarios. The Scandinavian countries - Sweden, Finland and Denmark - consistently occupy the top positions, indicating balanced performance across all three pillars of sustainability. In contrast, countries such as Luxembourg and Germany experience significant changes. They rank higher when economic factors are prioritized but drop significantly when environmental performance is emphasized. Similarly, Romania, Bulgaria, Poland or Greece consistently ranks lower, with only small improvements in specific scenarios. These findings suggest that while the composite index is generally robust, its sensitivity to the choice of weighting can affect the relative position of certain countries, especially those with unbalanced performance across sustainability dimensions, such as Latvia and Croatia.

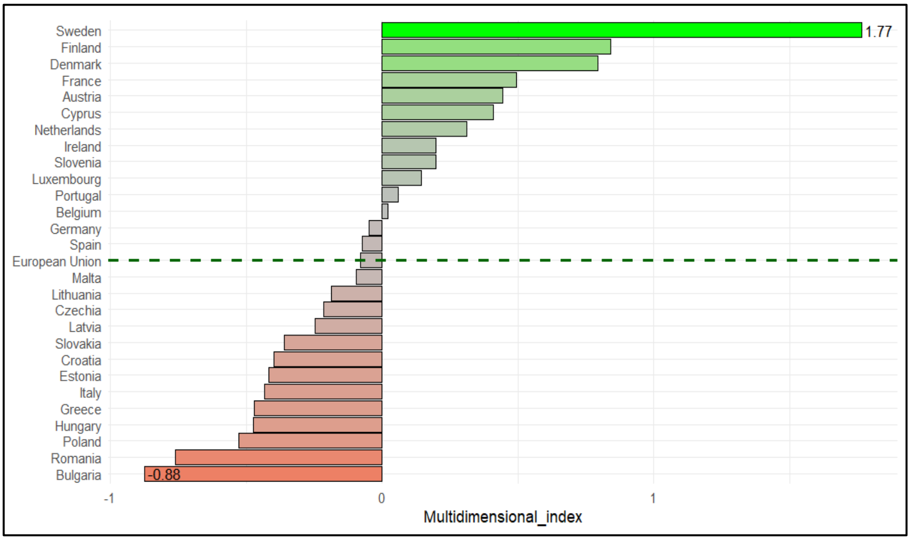

Figure 4: Multidimensional sustainability index of EU countries (2004–2023)
Source: Own elaboration by software RStudio

To verify the validity and explanatory power of the multidimensional index created, we performed a correlation analysis (Spearman's correlation coefficient), in which we compared its relationship with selected economic, social, and environmental variables. The results revealed significant links that support the relevance of the indicators used in the construction of the index. The multidimensional index shows a strong positive correlation with average Real GDP (*rho* = 0.82), Gross Domestic expenditure on research and development (*rho* = 0.79), and Tertiary educational attainment (*rho* = 0.61). These results show that economic performance, innovation potential, and education levels are significantly related to the composite development rate measured by the index. Conversely, the index correlates negatively with the At-risk-of-poverty rate (*rho* = -0.58), which confirms its contrasting relationship to socioeconomic stability. Also important are the strong correlations between economic indicators, such as between Real GDP and Gross domestic expenditure on research and development (*rho* = 0.92) or between Gross domestic expenditure on research and development and Recycling rate of municipal waste (*rho* = 0.84), which may suggest synergistic links between the economy, innovation, and environmental efforts. These results provide a solid basis for further modelling and interpretation of the dynamics between economic, social, and environmental factors.

Finally, we applied hierarchical cluster analysis to identify groups of countries with similar sustainability profiles. We extracted four main clusters from the dendrogram (Figure 5), for which we then calculated the average values of individual indices, thus obtaining a typology of sustainability profiles within the European Union between 2004 and 2023. Based on the cluster analysis, EU countries were grouped into four typological clusters:

- Cluster 1 - Austria, Cyprus, Denmark, Finland, France, Sweden.
- Cluster 2 - Belgium, Germany, Ireland, Luxembourg, Netherlands.
- Cluster 3 - Bulgaria, Croatia, Latvia, Romania.
- Cluster 4 - Czechia, Estonia, Greece, Hungary, Italy, Lithuania, Malta, Poland, Portugal, Slovakia, Slovenia, Spain.

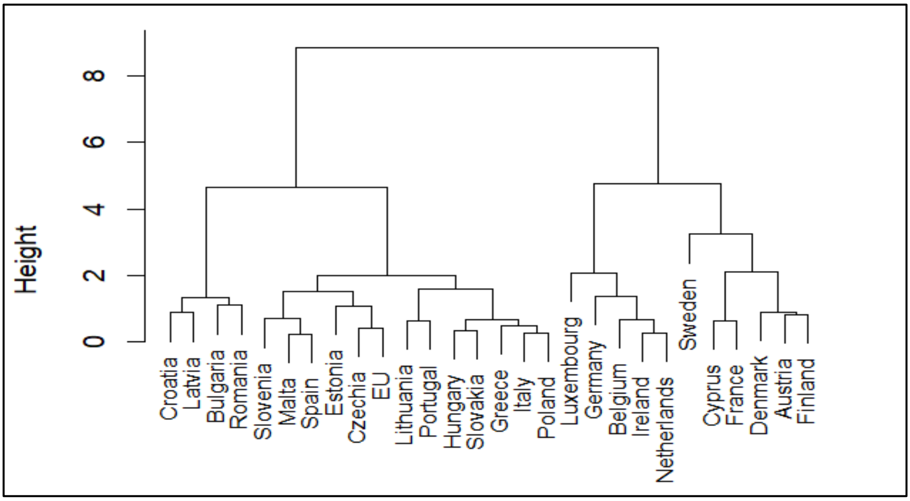

Figure 5: Hierarchical classification of countries based on economic, environmental and social profiles
Source: Own elaboration by software RStudio

Table 2: Cluster-wise average values of economic, environmental, and social indices

Cluster	Economics (Mean)	Environmental (Mean)	Social (Mean)
1.	1.00	0.43	0.94
2.	1.11	-1.60	0.86
3.	-1.00	1.06	-1.77
4.	-0.58	0.09	-0.22

Source: Own elaboration by software RStudio

Based on cluster analysis, countries were divided into four clusters according to average values in the economic, environmental, and social dimensions (Table 2). Cluster 1 represents countries with significantly above-average economic performance (1.00), a slightly positive environmental index (0.43) and high social standards (0.94). These are balanced and comprehensively developed countries. Cluster 2 is characterized by the highest economic score (1.11) and a relatively high social index (0.86) but lags significantly behind in the environmental area (-1.60). These countries are particularly strong in economic and social terms but show weaknesses in environmental terms. Cluster 3 consists of countries with the opposite profile, economically weaker (–1.00) but strong in environmental terms (1.06), while their social indicators are very weak (–1.77). These are countries with environmental potential but poor socioeconomic stability. Finally, cluster 4 includes countries with slightly below-average results in all three dimensions economic index (-0.58), environmental (0.09), social (-0.22), which indicates their average to stagnant development profile.

4. Conclusion

This study proposed a composite, multidimensional index for assessing the sustainability of EU countries in economic, environmental, and social terms. Based on standardized indicators and principal component analysis (PCA), three sub-indices were created and aggregated into a final index, enabling an objective comparison of EU countries.

The results demonstrate that Scandinavian countries such as Sweden, Finland, and Denmark are leading in sustainability, achieving above-average scores in all three dimensions. These countries are characterized by strong institutions, robust social systems, and consistent environmental policies. Austria, France, and the Netherlands also show positive results, exceeding the EU average, particularly in the economic and social areas, but with significant gaps in the environmental area. Conversely, several countries in Eastern and Southeastern Europe, such as Bulgaria, Romania, and Latvia, achieved the lowest multidimensional index scores, mainly due to poor social capital and limited economic productivity, although environmental scores were favorable in some cases. The V4 countries (Czechia, Slovakia, Hungary, and Poland) were concentrated in a cluster of countries with below average or average results across all three pillars, which confirms their persistent structural challenges. The strong correlations between the final index and underlying indicators also support the internal validity of the constructed index.

Cluster analysis identified four types of countries. Developed and balanced countries – cluster 1 - (Austria, Cyprus, Denmark, Finland, France, Sweden), economically strong countries with environmental deficits – cluster 2 - (Belgium, Germany, Ireland, Luxembourg, Netherlands), environmentally efficient countries with significant social problems – cluster 3 - (Bulgaria, Croatia, Latvia, Romania), and countries with an overall average profile – cluster 4 - (Czechia, Estonia, Greece, Hungary, Italy, Lithuania, Malta, Poland, Portugal, Slovakia, Slovenia, Spain.).

This typology highlights the internal diversity among EU member states and creates the conditions for different approaches to public policymaking in sustainable development. For countries in the first cluster, we recommend maintaining the current level of integration of environmental innovations into the economy. At the same time, they could expand regional cooperation and knowledge sharing so that less-performing countries from other clusters can adapt successful models to their own specific conditions and implement them effectively. The second cluster consists of economically strong countries with weaker environmental performance. In these cases, it would be appropriate to provide stronger support for the use of financial incentives for green investments and to expand low-carbon technologies in the manufacturing sector. Improvements in the environmental field could also be supported by more effective emissions regulations and environmental tax reform. Research and innovation funds should be targeted more towards climate solutions and the development of a circular economy. Ecologically efficient but economically and socially less developed countries belong to the third cluster. For them, it's important to focus on social investments, especially in healthcare and education. Investments in education policy can help increase economic performance in the long term. It is also necessary to support sustainable urban development and ensure balanced regional development. In view of the favorable results in the environmental pillar, it is appropriate to build on these advantages as a basis for green growth and the development of sustainable tourism. In the last fourth cluster, there are countries with average lagging results in all three dimensions. For this situation, we recommend integrated strategies that combine environmental, economic, and social goals. It is also crucial to invest in structural reforms and support the green transition in combination with digitalization as a dual engine for growth. These countries should approach the transition responsibly, with milestones for improvement in each area that are realistic and sustainable.

While the approach of equal weighting and PCA-based aggregation offers transparency, future research could explore time-dynamic models, and the integration of additional variables such as environmental taxes or the quality of public institutions. The proposed index could serve not only as a monitoring tool for progress toward sustainable development goals (SDGs), but also as an analytical framework for public policymaking at the regional or subnational level.

Acknowledgment: This paper was developed as part of the project GaPU DF/26 - Sustainability of European economies from the perspective of environmental taxes. Funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V05-00006. This paper was also supported by KEGA 010PU-4/2023 Innovation of the Course Entrepreneurship in Small and Medium-Sized Enterprises in the Context of Sustainability and Circularity and KEGA 024PU-4/2023 Preparation of an Innovative Study Programme Green Economy in the Field of Economics and Management.

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