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The green transition and workforce dynamics under demographic change: A comparative analysis of Romania in the European context

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Abstract

The intensification of climate change combined with demographic shifts poses significant challenges for sustainable economic development in the European Union (EU). This study examines Romania's position relative to other EU member states in the green transition, integrating economic, environmental, and demographic indicators into a comparative analytical framework. The research investigates the interrelationships among these indicators, with demographic dynamics conceptualized through the lens of the labor force. The analysis is based on data collected from Eurostat and Our World in Data, covering a sample of EU member states representing different levels of economic development. To identify similarities and differences across countries, scatter-plot analysis and agglomerative hierarchical clustering (AHC) were applied using five key indicators: gross domestic product per capita (purchasing power standard), CO_2 emissions per capita, primary energy consumption, the share of renewable energy, and the proportion of the active population to the total population. Based on these data, two research hypotheses were formulated on the relationship between economic development and sustainability performance. The results highlight the formation of clusters, generally comprising: (i) highly developed countries with high emissions; (ii) developed countries with effective green transition policies; and (iii) less developed economies, including Romania, characterized by relatively low emissions and increasing shares of renewable energy consumption. However, there are exceptions, such as Sweden and Denmark, which, despite being developed countries, cluster with Romania due to their high renewable energy consumption and low CO_2 emissions. Although Romania is gradually aligning with European sustainability policies, its transition remains constrained by structural limitations, energy dependency, and demographic and economic challenges.

Keywords: Sustainable development; Economic development; Demographic dynamics; Carbon dioxide emissions; Green energy

1. Introduction

In recent decades, the concept of sustainable development has taken center stage in the economic, social, and environmental strategies of European Union (EU) member states. Rapid economic development driven by intensive consumption of natural resources and unbalanced economic policies has generated major social, economic, and environmental challenges worldwide.[1,2] In many cases, economic growth has been prioritized without adequately considering the long-term consequences for environmental systems and the natural balance of the Earth.[3,4,5] As a result, environmental degradation, climate change, and resource depletion have become key global concerns that increasingly influence development strategies.

The growing pressure on natural resources has intensified academic interest in understanding the relationships among economic growth, energy consumption, and environmental quality. A large body of literature shows that economic growth is often associated with increased energy consumption and higher levels of CO_2 emissions, particularly in countries that rely heavily on fossil fuels.[6,7,8] At the same time, renewable energy sources are increasingly recognized as essential tools for reducing greenhouse gas emissions while supporting sustainable economic development.[9,10,11,12,13]

The complex relationship among economic growth, energy consumption, and environmental degradation has been widely discussed in the literature through the environmental Kuznets curve (EKC) hypothesis. According to this hypothesis, environmental degradation initially increases with economic growth but declines after a certain income threshold is reached.[14,15,16] Empirical evidence suggests that technological innovation, energy efficiency improvements, and structural changes in economies can help decouple economic growth from environmental degradation.[17,18,19]

Recent studies have also emphasized the importance of renewable energy adoption in mitigating climate change and improving environmental sustainability. Increasing the share of renewable energy in the energy mix can significantly reduce carbon emissions while promoting long-term economic stability.[20,21,22] Moreover, renewable energy investments generate positive spillover effects across countries and regions, contributing to sustainable development and environmental protection.[23,24]

Population dynamics and demographic change also play an important role in shaping environmental outcomes. Population growth, urbanization, and industrialization contribute to increased energy demand and environmental pressure.[25,26] At the same time, migration and demographic aging can affect the structure of labor markets and economic productivity, influencing the capacity of countries to implement sustainable policies.[27,28] In this context, the transition toward a green economy is no longer simply a policy option but a strategic necessity.

The literature addresses consumption reduction from several perspectives. While some studies focus on identifying solutions to reduce household consumption, others focus on extending these measures beyond domestic or private consumption.[29,30]

Recent contributions to the literature emphasize that the transition should not be seen solely as a decarbonization process but as a broader structural transformation involving technological innovation, institutional adaptation, economic competitiveness, and social cohesion. The current debate increasingly focuses on the capacity of European countries to combine climate objectives with economic resilience, energy security, geopolitical aspects, and regional development. In this context, the transition is perceived as a long-term process that reshapes production, labor markets, and resource consumption patterns, generating both opportunities and adjustment costs across countries and regions. The success of this transformation depends not only on the implementation of renewable energy technologies, but also on how countries adapt to new development models.

At the same time, studies at the European level highlight the importance of the demographic dimension and, by extension, the labor market in the energy transition process. The expansion of renewable energy sectors creates new employment opportunities, while generating challenges related to labor mobility, skills mismatches, and regional inequalities. Consequently, the transition to climate neutrality implies a complex approach that combines environmental objectives with economic development and demographic sustainability.

The EU has implemented ambitious policies aimed at reducing greenhouse gas emissions and promoting renewable energy, particularly through the European Green Deal and the 2030 Agenda for Sustainable Development.[31,32] These initiatives emphasize the need to balance economic growth with environmental protection and social equity.

According to a study[33], significant differences exist between developed and less developed countries regarding sustainability performance, largely influenced by disparities in economic development, energy structures, and institutional capacity to implement environmental policies.

Despite the expansion of the theoretical framework on sustainability, the current literature shows gaps in terms of European-level analyses that simultaneously correlate economic, environmental, and demographic vectors to identify national trajectories in the complex process of the green transition. The specialized literature generally reveals a fragmentary nature of comparative studies. This multidimensional approach remains insufficiently explored, limiting the identification of how the interdependencies between demographic structures and economic resources condition, or do not condition, the success of transition reforms in the European context. Although several studies have analyzed individual links between these variables[34,35,36,37,38,39], comprehensive analyses integrating all these factors remain relatively scarce.

In this sense, the present study aims to address this gap by integrating indicators related to economic development, the share of the labor force in the total population, energy consumption, the use of renewable energy, and environmental performance in a relatively new comparative framework using agglomerative hierarchical clustering (AHC). The analysis captures Romania's position and identifies similarities and differences between countries at different stages of economic development and green transition.

The concept of sustainability transcends simple environmental protection, constituting a multidimensional structure that harmonizes economic development, social cohesion, and ecosystem conservation. In this paradigm, sustainable development is not limited to economic expansion, but aims to optimize the use of natural resources, social inclusion, and strengthen societal resilience in the long term. The literature emphasizes the dynamic nature of this process, in which economic, environmental, and demographic systems interact and influence each other.[40] Therefore, demographic aspects, such as population aging, labor force dynamics, and migration flows, become pillars of sustainability, influencing production, consumption patterns, energy demand, and the capacity to adapt to global structural transformations.

From this perspective, the green transition does not represent a simple substitution of conventional energy sources with renewable alternatives, but a long-term socio-economic and technological reconfiguration. A recent study emphasizes that the green transition should be understood as a co-evolution process in which technological innovation, institutional reforms, demographic changes, and economic restructuring interact, generating both opportunities and adjustment costs across societies.[41] The progress of EU member states on the path to the green transition is uneven, reflecting differences in levels of economic development, labor market structures, and the reconfiguration of energy systems. Consequently, the analysis of Romania's position in the European context involves a complex approach that correlates economic performance and environmental outcomes with specific demographic attributes of the labor force. This theoretical foundation supports the premise that variations in sustainability performance and the progress of the green transition are linked to both the stage of economic development and the demographic dynamics of each state.

Romania, as a member state of the EU, is part of this broader transition toward sustainable development. However, the process involves significant challenges, particularly for developing and transition economies that must balance economic growth objectives with environmental sustainability goals. According to recent studies, the Romanian energy system has become increasingly complex after 2016, making policy coordination and energy management more challenging.[42]

Furthermore, Eastern European countries face structural differences compared to Western European economies in terms of energy efficiency, technological innovation, and environmental policy implementation.[22,43] These disparities influence the pace of the green transition and the ability of countries to reduce emissions while maintaining economic growth.

This study aims to analyze the positioning of Romania within the EU from the perspectives of demographic dynamics and the transition toward a green economy. The analyses compared Romania with countries with similar economic structures, as well as with more advanced economies characterized by higher levels of sustainability and environmental performance.

The study evaluates several economic, environmental, and energy indicators, including gross domestic product (GDP) per capita, the degree of industrialization, renewable energy consumption, and CO_2 emission trends. These indicators reflect the complexity of the green transition and the multiple factors that influence sustainable development.

Although Romania has made progress in certain areas, it continues to face significant challenges, such as energy dependency, demographic decline, and labor migration. These factors directly influence the country's capacity to implement a sustainable development model and to adapt to the EU's environmental policies.

These aspects highlight the need for an analytical approach that accounts for the interactions between economic development, environmental performance, and demographic changes through the lens of the labor force. In accordance with the sustainability perspective specified in the study, environmental performance cannot be assessed independently of economic development and demographic conditions, as these dimensions together shape countries' capacity to pursue sustainable development paths in the long term. Given the multidimensional nature of sustainability and the heterogeneity among EU member states, we considered a comparative approach based on AHC useful to identify groups of countries with similar economic, environmental, and demographic characteristics. In this context, we formulated the following hypotheses (H):

(i) H1: There are significant differences between groups of countries with high GDP per capita and those with low GDP per capita in terms of environmental sustainability.
(ii) H2: States with advanced green economies tend to form distinct clusters compared with those with a high dependence on fossil resources.

Through this analysis, the study aims to determine whether Romania aligns more closely with less developed economies in the green transition or with more advanced economies that have successfully implemented sustainable development policies.

The results are expected to highlight three main categories of countries: countries with strong economies but low shares of renewable energy and high CO_2 emissions, developed countries that represent good practices in terms of emission reductions and renewable energy adoption, and countries with less developed economies where both CO_2 emissions and renewable energy shares remain at moderate levels.

2. Materials and methods

2.1. Materials

To achieve the proposed objective, a sample of the top- and bottom-eight EU27 countries, ranked by GDP per capita (purchasing power standard [PPS]) in 2023, was selected. This approach allowed us to compare advanced economies with emerging economies, providing a complex perspective on the relationship between economic development and environmental sustainability. We also made this selection because the top eight countries included four recognized for their good practices in the green economy (Sweden, Denmark, Austria, and the Netherlands), which serve as reference models for effective sustainable policies.[44] Although they did not experience significant growth during the analyzed period, Sweden, Austria, Germany, and Denmark already had a strong renewable energy sector as early as 2001.[45,46]

The data used in this study were collected from the EUROSTAT and Our World in Data databases, which offer comprehensive and internationally comparable statistics on economic, demographic, energy, and environmental indicators.

2.2. Methods

As a first step, scatter plots were used to correlate the values of two indicators to identify similar developments across the countries analyzed. The next step was to group countries into clusters using the AHC method, aiming to identify patterns of similarity between countries based on relevant indicators, such as CO_2 emissions per capita, GDP per capita (PPS), working-age population as a share of the total population, primary energy consumption, and share of renewable energy in total consumption.

2.3. Statistical analysis

Before performing the AHC analysis, the data (Table 1) were standardized to ensure comparability across indicators.

This standardization process was performed with XLSTAT in Microsoft Excel (Microsoft, United States of America), and the results are presented in Table 2. The standardization of these data played an important role in the conduct of the AHC analysis, as it enabled countries to be compared and eliminated the influence of absolute value differences. In this way, models were shaped by relevant similarities and differences among European economies, highlighting the connections and particularities of each country in the context of the green transition.

3. Results

The identification of Romania's profile within the European landscape of the green transition and in the context of demographic changes was achieved through a dual approach, the results of which are detailed in the following subchapters.

3.1. Similarities across EU member countries based on the association between two variables

Similar developments across the countries analyzed were identified using scatter plots, which allowed us to observe relationships between the selected indicators and to identify possible clusters of countries. This analysis helps identify general trends, relationships between variables, and how countries and clusters differ by energy economies and energy transitions.

To determine whether the group of countries analyzed in this study sustainably improved their Human Development Index (HDI), without economic development affecting the environment, we considered it necessary to correlate the HDI with the Sustainable Development Goals (SDG) Index (Figure 1). We also considered this analysis relevant

Table 1. Study indicators

Country	CO_2 emissions per capita (tonnes)	GDP per capita (PPS)	Share of working-age pop. in total pop. (%)	Primary energy cons. (TWh)	Share of renewable energy (%)
Belgium	7.12	118	63.81	3.57	14.74
Bulgaria	5.31	64	62.33	2.57	22.55
Denmark	4.58	125	63.58	2.58	44.40
Germany	7.05	116	63.74	2.85	21.55
Ireland	6.63	213	65.47	2.65	15.25
Greece	5.39	69	63.68	1.91	25.27
Croatia	4.50	76	63.01	2.21	28.05
Latvia	3.46	70	63.07	2.27	43.22
Luxembourg	10.51	237	69.27	5.48	14.36
Hungary	4.15	77	64.95	2.31	17.12
Netherlands	6.56	133	64.47	3.01	17.15
Austria	6.42	120	66.00	3.21	40.84
Poland	7.46	77	64.69	2.55	16.56
Romania	3.57	78	64.18	1.57	25.76
Slovakia	5.57	74	66.06	2.85	16.99
Sweden	3.46	114	62.21	3.93	66.39

Source: Data from EUROSTAT and Our World in Data.
Abbreviations: cons.: Consumption; GDP: Gross domestic product; pop.: Population; PPS: Purchasing power standard.

Table 2. Standardized data

Country	CO_2 emissions per capita	GDP per capita (PPS)	Share of working-age pop. in total pop.	Primary energy cons.	Share of renewable energy
Belgium (BE)	0.7	0.2	0.3	0.8	0.8
Bulgaria (BG)	0.2	0.9	1.2	0.3	0.3
Denmark (DK)	0.6	0.3	0.5	0.3	1.2
Germany (DE)	0.7	0.1	0.4	0.0	0.4
Ireland (IE)	0.5	2.0	0.6	0.2	0.8
Greece (EL)	0.2	0.8	0.4	1.0	0.1
Croatia (HR)	0.7	0.7	0.8	0.7	0.1
Latvia (LV)	1.2	0.8	0.8	0.6	1.1
Luxembourg (LU)	2.6	2.5	2.8	2.9	0.9
Hungary (HU)	0.9	0.7	0.3	0.6	0.7
Netherlands (NL)	0.4	0.5	0.0	0.2	0.7
Austria (AT)	0.4	0.2	0.9	0.4	1.0
Poland (PL)	0.9	0.7	0.2	0.3	0.7
Romania (RO)	1.2	0.6	0.1	1.4	0.1
Slovakia (SK)	0.1	0.7	0.9	0.0	0.7
Sweden (SE)	1.2	0.1	1.3	1.2	2.7

Abbreviations: cons.: Consumption; GDP: Gross domestic product; pop.: Population; PPS: Purchasing power standard.

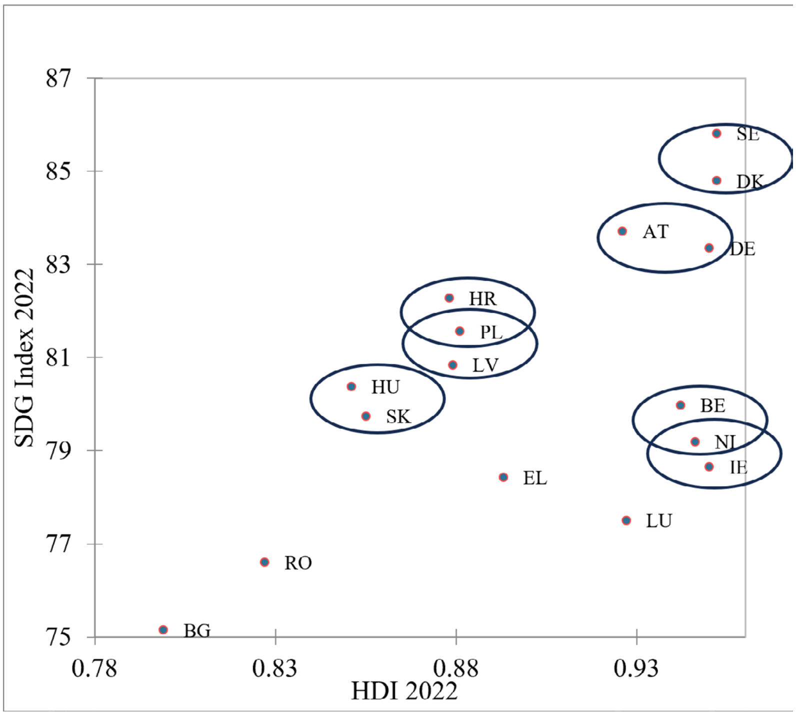

Figure 1. Relationship between the Human Development Index (HDI) and the Sustainable Development Goals (SDG) Index for the 16 countries analyzed in 2022

because the HDI measures human well-being but does not take into account environmental impacts, while the SDG Index assesses countries' progress toward the SDGs, including factors essential to the green transition, such as renewable energy, climate policies, and sustainable consumption.[47]

There is a generally positive relationship between the HDI and the SDG Index, suggesting that countries with higher HDIs tend to perform better in achieving the SDGs. In general, countries with strong, sustainable, high-HDI economies, such as Sweden, Denmark, and Germany, reported high SDG Index scores. Countries with lower HDIs and less developed economies, such as Bulgaria and Romania, reported lower SDG Index scores, suggesting a greater challenge in achieving the sustainability goals. However, there are exceptions, such as Luxembourg, which reported a high HDI but a relatively low SDG Index compared to other developed countries, due to strong economic development based on high resource consumption.

Next, we examined relationships between indicators such as CO_2 emissions per capita, GDP per capita (PPS), working population, primary energy consumption, and the share of renewable energy. These analyses revealed general trends, the relationships between variables, and how countries and clusters differ in their economies and energy transitions.

Figure 2 illustrates the relationship between economic development (GDP per capita [PPS]) and CO_2 emissions per capita. The analysis distinguishes countries by their levels of economic development and environmental impact. On the one hand, we observed a cluster of countries with high GDP per capita (PPS) and high CO_2 emissions per capita, such as Luxembourg, Germany, Belgium, and the Netherlands, where economic growth is strongly linked to high energy consumption. On the other hand, countries such as Romania, Bulgaria, Hungary, and Latvia had low GDP per capita (PPS) and low CO_2 emissions per capita, indicating lower levels of industrialization or less dependence on polluting energy sources. Sweden and Denmark, in contrast, showed that a strong economy can also be sustainable, growing while maintaining low CO_2 emissions per capita due to widespread renewable energy use.

Figure 3 shows the relationship between a country's active population structure and the level of CO_2 emissions per capita. Countries such as Germany and Poland, with larger working populations, reported high CO_2 emissions per capita, suggesting that intense economic activity significantly influences pollution levels. Romania,

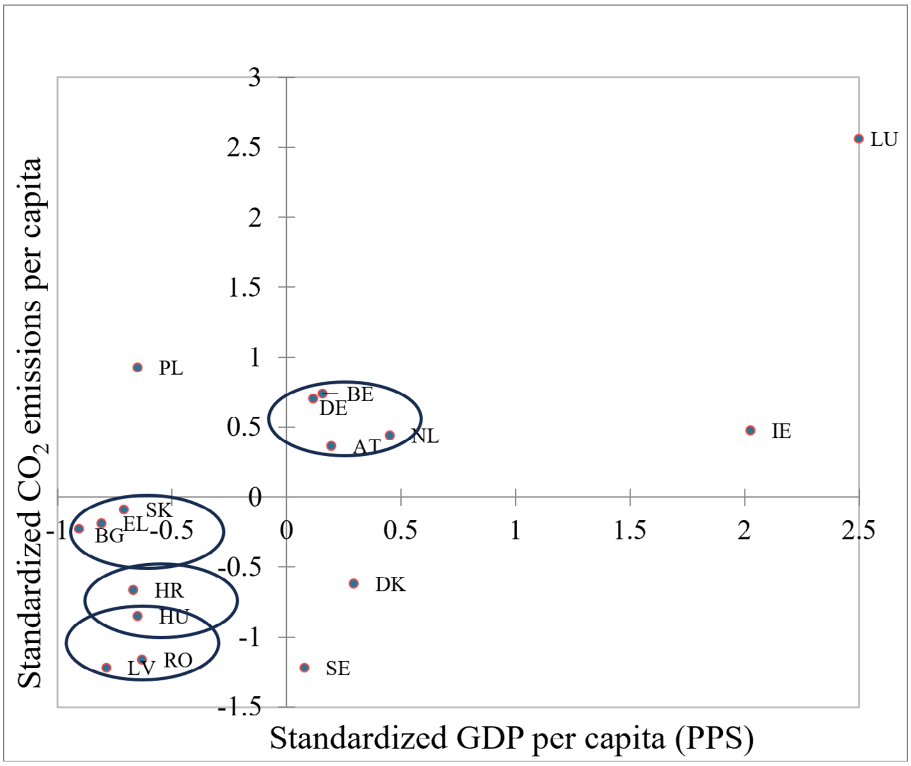

Figure 2. Scatter plot of standardized CO_2 emissions per capita vs. standardized gross domestic product (GDP) per capita (purchasing power standard [PPS])

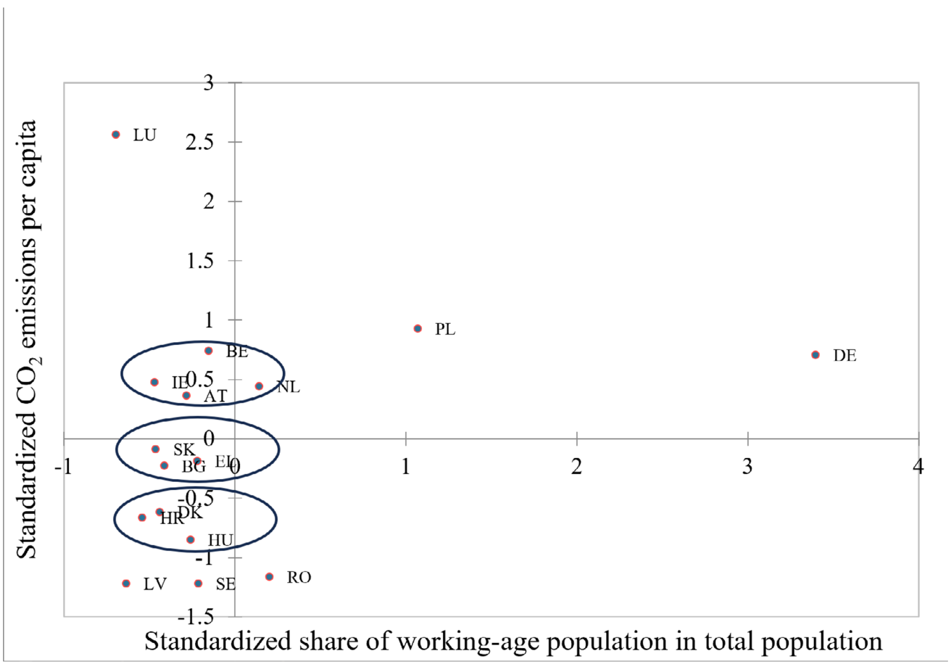

Figure 3. Scatter plot of standardized CO_2 emissions per capita vs. standardized share of working-age population in total population

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Bulgaria, Hungary, Latvia, Sweden, and Denmark had low CO_2 emissions per capita, despite differences in the structure of their working populations. Slovakia, Bulgaria, and Greece had a similar profile, characterized by medium CO_2 emissions per capita and economies in transition. Both Romania and Latvia were in the same group as Sweden, allowing them to develop without following the pattern of high-polluting countries. On the other hand, Denmark and Sweden showed that a strong economy can operate efficiently while achieving low CO_2 emissions per capita through extensive use of renewable energy, and are good examples for Romania to follow. Luxembourg clearly differentiated itself from the other countries, with the highest CO_2 emissions per capita but a low share of the working population. This suggests that the high level of CO_2 emissions per capita is not necessarily influenced by the size of the labor force, but rather by a high energy consumption per capita, typical of a service-based economy and a high standard of living. Similar developmental patterns were observed in Belgium, the Netherlands, Ireland, and Austria; Slovakia, Greece, and Bulgaria; Denmark, Croatia, and Hungary; and Romania, Sweden, and Latvia.

The relationship between primary energy consumption and CO_2 emissions per capita, captured in Figure 4, can suggest whether higher energy consumption leads to higher emissions. Countries with high energy consumption, such as Luxembourg, Germany, and Belgium, also had high CO_2 emissions per capita, indicating a strong dependence on traditional energy sources. In contrast, Romania and Latvia had low energy consumption and low CO_2 emissions per capita, and were therefore not major sources of pollution. Luxembourg clearly stood out as having the highest energy consumption and CO_2 emissions per capita, probably due to a high standard of living and high energy consumption. Romania, on the other hand, has the opportunity to grow its economy without following the polluting model of other countries by investing in renewable energy. Similar developmental patterns were observed in Denmark, Croatia, and Hungary; Slovakia and Bulgaria; Poland, Germany, and Ireland; and the Netherlands, Austria, and Belgium.

Figure 5 presents the relationship between renewable energy use and CO_2 emissions per capita, highlighting how countries are succeeding or failing to reduce pollution through the transition to green energy. Countries that use more renewable energy, such as Sweden and Latvia, had lower CO_2 emissions per capita, indicating that the transition to green energy reduces pollution. On the other hand, Luxembourg, Poland, Germany, and Belgium had high CO_2 emissions per capita and low renewable energy use, indicating they heavily depend on fossil fuels. Romania and Hungary were in an intermediate position, with relatively low CO_2 emissions per capita and low renewable energy use. This shows that Romania has the potential to further reduce its environmental impact by investing in green energy sources. Similar developmental patterns were observed in Greece and Bulgaria; and Poland, Belgium, Germany, Ireland, and the Netherlands.

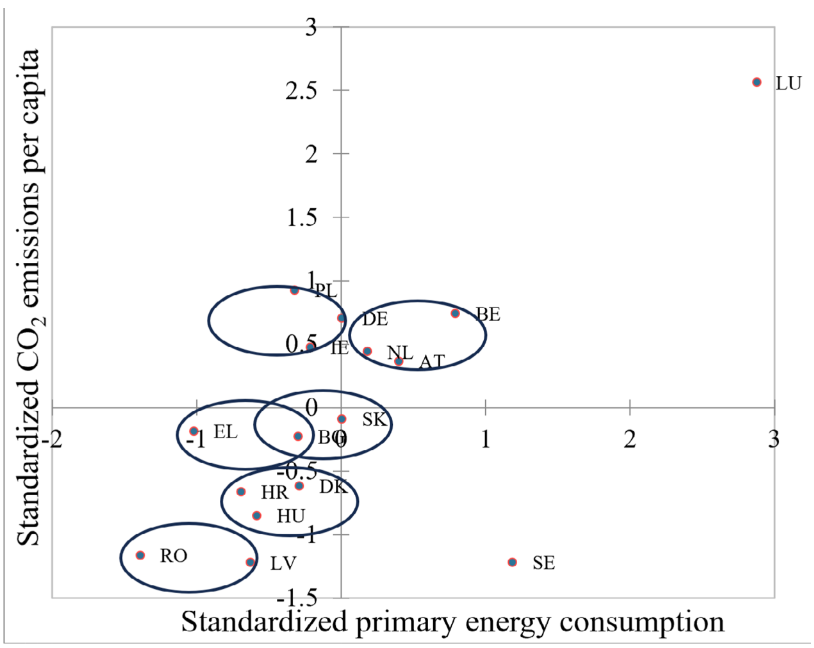

Figure 4. Scatter plot of standardized CO_2 emissions per capita vs. standardized primary energy consumption

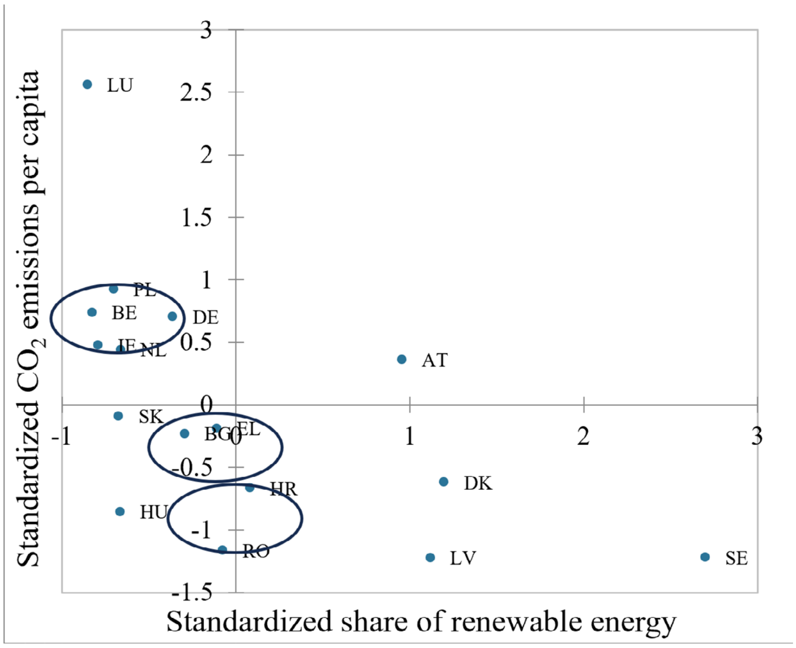

Figure 5. Scatter plot of CO_2 emissions per capita vs. the share of renewable energy

Given that countries with high GDP have the capacity to finance the green transition, which implies the generation of new jobs in the green sector that boost economic sustainability, Figure 6 shows the relationship between the two indicators. In general, countries with strong, sustainable economies had high GDP per capita (PPS) and high employment in the environmental goods and services sector. The exceptions were Ireland and Luxembourg, which, despite having the highest GDP per capita (PPS), had high CO_2 emissions per capita and low employment in the environmental goods and services sector. Eastern European countries had low GDP per capita (PPS) and low employment in this sector. Germany had the largest environmental workforce but not the highest GDP per capita (PPS). This analysis emphasizes that a developed economy does not necessarily imply a large number of employees in the environmental sector, but rather a balance between economic policies and the green transition. Similar developmental patterns were observed in the Netherlands, Sweden, Denmark, Austria, and Belgium; Slovakia, Greece, Romania, Hungary, Latvia, and Bulgaria; and Ireland and Luxembourg.

To further assess the relationship between environmental pressure and pollution, we analyzed the relationship between greenhouse gas emission intensity and waste generation in different European countries. Luxembourg, Germany, Austria, Belgium, and Ireland had low air emission intensities while generating less waste (Figure 7). In contrast, the Netherlands had low air emission intensities but the highest waste generation, indicating high consumption coupled with efficient emissions management. Countries with less developed economies, such as Hungary, Latvia, and Romania, had relatively high air emission intensities but generated less waste. This can be explained by greater reliance on fossil fuels and lower consumption, or by the use of less efficient technologies. Bulgaria had high values for both indicators, while Poland had low waste generation but high air emissions intensities.

3.2. Agglomerative hierarchical clustering analysis

The first output of the AHC method includes summary statistics (Table 3).

Table 3 presents an overview of the main statistical characteristics of the analyzed variables. All 16 observations were complete with no missing data. The values of each variable ranged from a minimum of 1.4 to a maximum of 2.9.

Next, we analyzed the correlation matrix, which shows the correlations among the five variables. A correlation coefficient ranges from −1 to 1, indicating the strength and direction of the relationship between variables (Table 4).

We observed several strong positive correlations, most notably a coefficient of 0.7 between, for example, CO_2 emissions per capita and GDP per capita (PPS), indicating

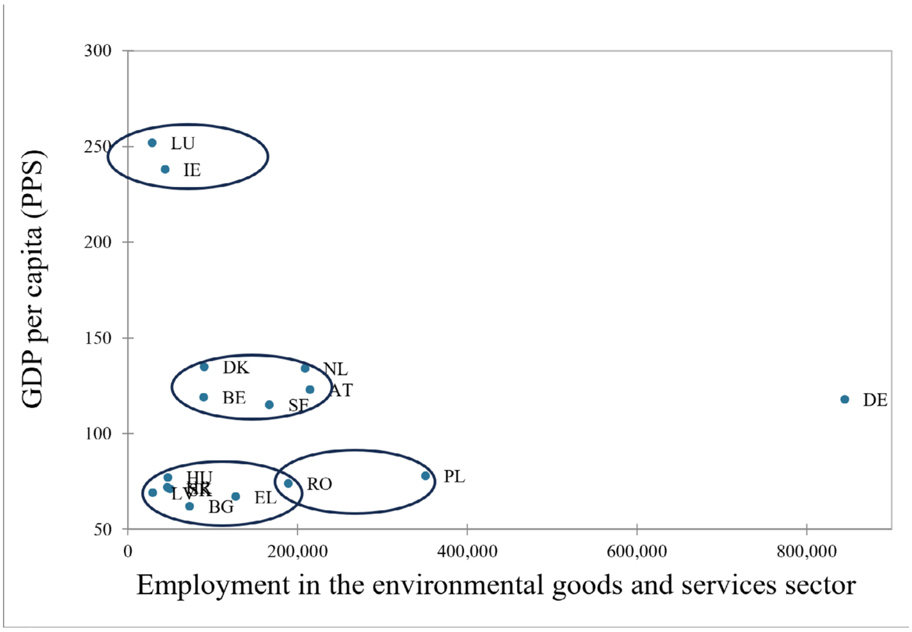

Figure 6. Scatter plot of gross domestic product (GDP) per capita (purchasing power standard [PPS]) vs. employment in the environmental goods and services sector

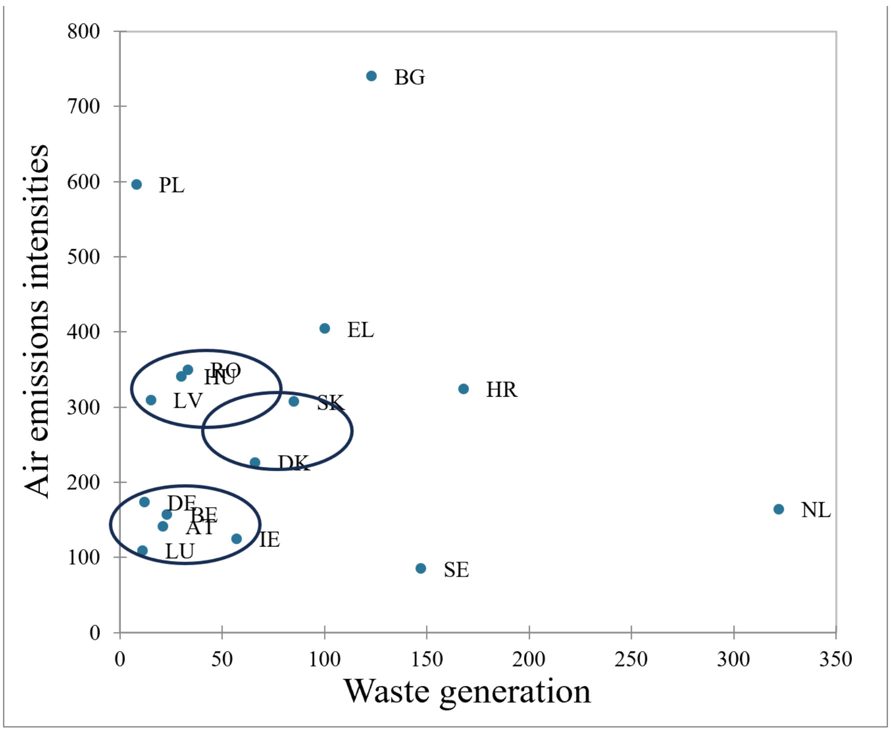

Figure 7. Scatter plot of air emission intensities (greenhouse gases) vs. waste generation

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Table 3. Agglomerative hierarchical clustering summary statistics

Variable	Comments	Obs. with missing data	Obs. without missing data	Minimum	Maximum
CO_2 emissions per capita	16	0	16	1.2	2.6
GDP per capita (PPS)	16	0	16	0.9	2.5
Share of working-age pop. in total pop.	16	0	16	1.3	2.8
Primary energy consumption	16	0	16	1.4	2.9
Share of renewable energy	16	0	16	0.9	2.7

Abbreviations: GDP: Gross domestic product; obs.: Observation; pop.: Population; PPS: Purchasing power standard.

Table 4. Correlation matrix

Parameters	CO_2 emissions per capita	GDP per capita (PPS)	Share of working-age pop. in total pop.	Primary energy cons.	Share of renewable energy
CO_2 emissions per capita	1	0.7	0.7	0.7	−0.6
GDP per capita (PPS)	0.7	1	0.6	0.7	−0.2
Share of working-age pop. in total pop.	0.7	0.6	1	0.6	−0.5
Primary energy cons.	0.7	0.7	0.6	1	0.0
Share of renewable energy	−0.6	−0.2	−0.5	0.0	1

Abbreviations: cons.: Consumption; GDP: Gross domestic product; pop.: Population; PPS: Purchasing power standard.

that more developed economies tend to generate higher emissions. This dynamic stems from the fact that higher GDP often reflects intense economic activity and elevated energy consumption, particularly from traditional sources. This dependence on fossil fuels is further underscored by a strong positive correlation of 0.7 between CO_2 emissions per capita and primary energy consumption, confirming that increased energy use drives higher emission levels. Interestingly, a similarly strong correlation of 0.7 existed between CO_2 emissions per capita and the share of the working-age population in the total population. This demographic-environmental link implies that countries with a larger working-age population, such as Germany, exhibit higher emissions, while those with a shrinking active population, such as Romania, have lower emissions. The data also highlight negative correlations, such as a coefficient of −0.6 between CO_2 emissions and the share of renewable energy. This correlation indicates the benefits of the transition to clean energy sources, as countries that expand their renewable energy capacity naturally reduce their emissions. Romania has a moderate share of renewable energy and low CO_2 emissions per capita. The value of the coefficients was not only determined by the green transition but also by its low level of industrialization, suggesting significant potential for further emission reductions through the expansion of green energy. In addition, a weak negative correlation of −0.2 between GDP per capita (PPS) and renewable energy reveals that higher GDP per capita does not inherently guarantee a higher share of renewable energy. This indicates widespread diversity in energy mixes across developed economies and suggests that investments in green sources depend largely on specific national strategies and resource availability. Finally, a moderate negative correlation of −0.5 linked the share of the working-age population to the share of renewable energy, illustrating an inverse relationship: countries with a larger active labor force tend to have a lower share of renewable energy in their energy mix.

To better understand how similar or different the countries analyzed are from Romania in terms of the green transition, a matrix of Euclidean distances was calculated to help measure the “distances” between countries based on the five standardized key indicators: CO_2 emissions per capita, GDP per capita (PPS), population, primary energy consumption, and share of renewable energy. Small distances indicate countries with similar profiles, while large distances signal significant differences in economic and energy structure (Table 5).

Romania came closest to countries such as Hungary, Greece, Croatia, and Latvia, reflecting a shared economic and energy pathway within the European context. This

Table 5. Proximity matrix

Countries	Belgium	Bulgaria	Denmark	Germany	Ireland	Greece	Croatia	Latvia	Luxembourg	Hungary	Netherlands	Austria	Poland	Romania	Slovakia	Sweden
Belgium	0	2.1	2.7	0.9	2.3	2.4	2.4	3.3	4.8	2.4	0.8	2.2	1.5	3.1	1.9	4.2
Bulgaria	2.1	0	2.1	1.6	3.6	1.1	0.8	1.8	6.8	1.7	2.0	2.8	1.8	1.8	2.2	3.6
Denmark	2.7	2.1	0	2.1	3.1	1.9	1.6	1.3	6.3	2.3	2.3	1.9	2.7	2.0	2.6	2.3
Germany	0.9	1.6	2.1	0	2.2	1.7	1.8	2.7	5.3	2.0	0.7	1.9	1.1	2.5	1.8	3.9
Ireland	2.3	3.6	3.1	2.2	0	3.3	3.4	4.1	4.3	3.0	1.7	2.6	2.8	3.5	2.8	4.9
Greece	2.4	1.1	1.9	1.7	3.3	0	0.7	1.7	6.7	1.2	2.0	2.5	1.6	1.1	1.8	3.9
Croatia	2.4	0.8	1.6	1.8	3.4	0.7	0	1.2	6.9	1.4	2.1	2.6	2.1	1.1	2.1	3.4
Latvia	3.3	1.8	1.3	2.7	4.1	1.7	1.2	0	7.3	2.1	3.0	2.7	3.0	1.6	2.8	2.6
Luxembourg	4.8	6.8	6.3	5.3	4.3	6.7	6.9	7.3	0	6.3	4.9	4.8	5.5	7.1	5.4	7.2
Hungary	2.4	1.7	2.3	2.0	3.0	1.2	1.4	2.1	6.3	0	1.9	2.5	1.8	1.1	1.2	4.2
Netherlands	0.8	2.0	2.3	0.7	1.7	2.0	2.1	3.0	4.9	1.9	0	1.9	1.3	2.6	1.6	4.1
Austria	2.2	2.8	1.9	1.9	2.6	2.5	2.6	2.7	4.8	2.5	1.9	0	2.2	2.9	2.0	3.3
Poland	1.5	1.8	2.7	1.1	2.8	1.6	2.1	3.0	5.5	1.8	1.3	2.2	0	2.4	1.3	4.6
Romania	3.1	1.8	2.0	2.5	3.5	1.1	1.1	1.6	7.1	1.1	2.6	2.9	2.4	0	2.2	4.0
Slovakia	1.9	2.2	2.6	1.8	2.8	1.8	2.1	2.8	5.4	1.2	1.6	2.0	1.3	2.2	0	4.4
Sweden	4.2	3.6	2.3	3.9	4.9	3.9	3.4	2.6	7.2	4.2	4.1	3.3	4.6	4.0	4.4	0

group of nations is primarily characterized by a moderate transition to green energy. Although efforts to shift toward renewable sources are clearly underway, their pace remains less accelerated than that of Northern or Western European economies. Furthermore, these countries maintain relatively moderate CO_2 emissions per capita, occupying an intermediate stage between their industrial past and a sustainable future, due to balanced energy consumption and a moderate degree of industrialization. Finally, this energy profile is structurally tied to their economic baseline, as these countries exhibited a low GDP per capita (PPS) in the European context. On the other hand, Romania differed significantly from countries such as Luxembourg (7.1), Sweden (4.0), Ireland (3.5), and Belgium (3.1). Both Luxembourg and Ireland had extremely high GDP per capita (PPS), reflecting the existence of niche economies, possibly focused on financial services and advanced technologies. In the case of Sweden, the differences stem in particular from the high share of renewable energy. This country has an almost climate-neutral economy. Belgium stood out as having the third-highest CO_2 emissions per capita and primary energy consumption.

It can be concluded that Romania is among the less developed countries in Central and Eastern Europe and is significantly behind European leaders in sustainability. On the one hand, it has many characteristics in common with countries undergoing economic and energy transitions; on the other hand, differences from advanced economies underscore the challenges and opportunities for catch-up through investments in green energy, sustainable technologies, and forward-looking economic policies.

The next step was to construct the dendrogram, grouping countries by demographic, economic, and energy characteristics into three main clusters (Figure 8).

Cluster 1 comprises countries with developed economies, such as Ireland, Austria, Belgium, Germany, and the Netherlands, characterized by high CO_2 emissions per capita and high primary energy consumption, and most of them have high GDP per capita (PPS). Poland and Slovakia are in this cluster due to high CO_2 emissions per capita and a low share of renewable energy.

Cluster 2 comprises Sweden, Denmark, Latvia, Bulgaria, Greece, Croatia, Hungary, and Romania. Among them,

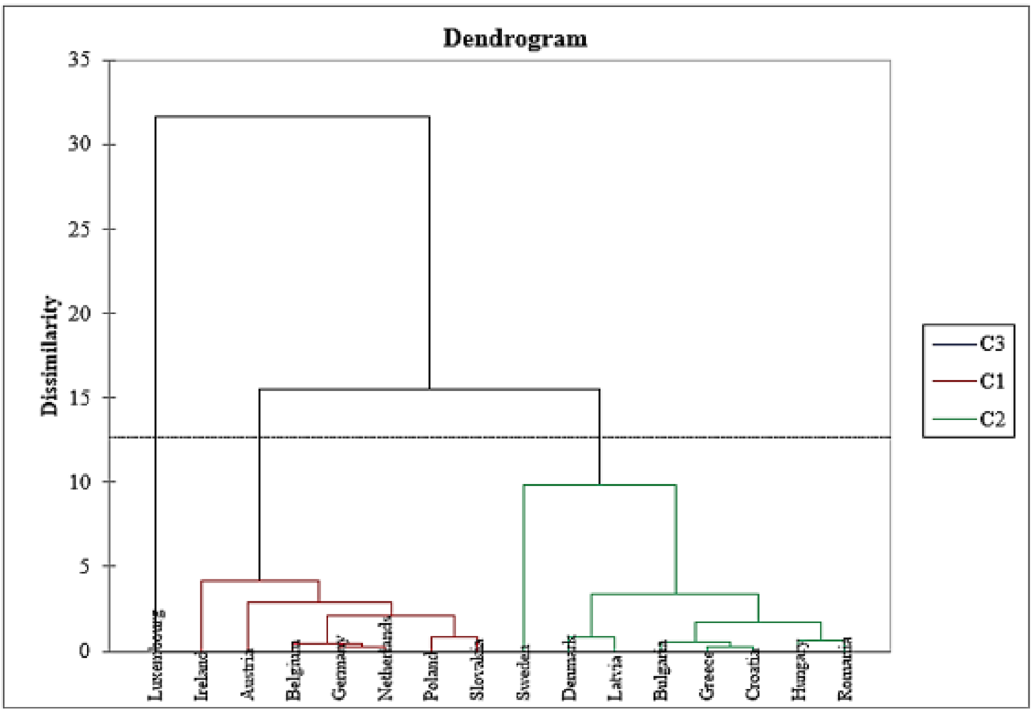

Figure 8. Agglomerative hierarchical clustering
Notes: C1: Cluster 1; C2: Cluster 2; C3: Cluster 3.

Latvia, Bulgaria, Greece, Croatia, Hungary, and Romania are countries with less developed economies but a high share of renewable energy and low CO_2 emissions per capita. The Nordic countries (e.g., Sweden and Denmark), although leaders in renewable energy use and with high GDP per capita (PPS), appeared in the same cluster as Romania due to the similarities mentioned above.

Clustering not only reflects individual performance on a given indicator but also complex patterns of similarity between several variables. Energy efficiency and low CO_2 emissions per capita seem to be linking factors between some Nordic countries and Romania, despite obvious differences in renewable energy use. Both demographic structure and economic factors add a layer of coherence in cluster formation.

Cluster 3 highlights the significant differences in the indicator values for Luxembourg compared to the other countries. Luxembourg had an extremely high level of CO_2 emissions per capita compared to other countries due to intensive energy consumption and an infrastructure reliant on private transport, given the small size of the country and the influx of cross-border commuters. At the same time, the extremely high GDP per capita (PPS) indicates a prosperous economy, supported by a strong financial sector, a favorable tax environment, and high productivity. Another distinctive feature is its high proportion of the working population. Luxembourg attracts a considerable number of workers from neighboring countries, ranking above the European average in terms of the share of the working-age population. The high energy consumption reflects both its standard of living and the country's economic specificity, with high-value-added industries and services, as well as high personal consumption. Despite its economic performance, Luxembourg had an extremely low share of renewable energy. This reliance on traditional energy sources indicates a need to transition to sustainable sources in line with European climate objectives. This analysis highlights where Romania stands compared to other European countries and where it can go to become more sustainable.

To assess more clearly the grouping of countries within each cluster and the differences between clusters, we proceeded to elaborate the inertia decomposition. To identify the dominant features that differentiate the clusters, we analyzed their centroids (Table 6).

The cluster centroids represent the average characteristics of each country group. Countries in Cluster 1 differ from those in Cluster 2 (except Poland and Slovakia), characterized by high CO_2 emissions per capita and a lower share of renewable energy. This separation shows the contrast between less-developed and highly developed economies. Cluster 2, which includes Romania, groups countries with moderate economic and energy profiles, without major extremes, with CO_2 emissions per capita, GDP per capita (PPS), and energy consumption close to the overall average (except Sweden and Denmark). Cluster 3, which includes Luxembourg, is clearly different from the other two clusters.

Table 7 lists the central objects of each cluster, i.e., the elements (countries) that best reflect the specific characteristics of each cluster.

The central objects of the clusters show which countries are representative of each group. While the Netherlands is the representative country for Cluster 1, Croatia best reflects the characteristics of Cluster 2. Romania has a similar profile to Croatia, sharing comparable economic and energy features. In contrast, Luxembourg (Cluster 3) differs significantly from the rest due to its high GDP per capita (PPS) and CO_2 emissions per capita. This comparison highlights the differences between developing and developed economies in the context of the energy transition.

To identify the distribution of countries within each cluster and the coherence of the clusters, results per cluster were analyzed, including the number of countries, internal variation, and distances to the center of each cluster (Table 8).

Analysis of the results by cluster shows that Romania is part of Cluster 2, together with countries such as Bulgaria,

Table 6. Cluster centroids

Cluster	CO_2 emissions per capita	GDP per capita (PPS)	Share of working-age population in total population	Primary energy consumption	Share of renewable energy	Sum of weights	Within-cluster variance
1	0.5	0.2	0.3	0.1	0.4	7.0	1.8
2	0.8	0.5	0.6	0.5	0.5	8.0	2.5
3	2.6	2.5	2.8	2.9	0.9	1.0	0.0

Abbreviations: GDP: Gross domestic product; PPS: Purchasing power standard.

Table 7. The central objects of the clusters

Cluster	CO_2 emissions per capita	GDP per capita (PPS)	Share of working-age population in total population	Primary energy consumption	Share of renewable energy
1 (Netherlands)	0.4	0.5	0.0	0.2	0.7
2 (Croatia)	0.7	0.7	0.8	0.7	0.1
3 (Luxembourg)	2.6	2.5	2.8	2.9	0.9

Abbreviations: GDP: Gross domestic product; PPS: Purchasing power standard.

Table 8. Results by clusters

Parameter	Cluster		
	1	2	3
Number of objects by cluster	7	8	1
Sum of weights	7	8	1
Within-cluster variance	1.8	2.5	0.0
Minimum distance to centroid	0.4	0.6	0.0
Average distance to centroid	1.1	1.3	0.0
Maximum distance to centroid	1.9	2.9	0.0
Countries	Belgium, Germany, Ireland, the Netherlands, Austria, Poland, Slovakia	Bulgaria, Denmark, Greece, Croatia, Latvia, Hungary, Romania, Sweden	Luxembourg

Croatia, and Hungary, which have diverse economies and energy mixes but share common features, such as moderate GDP per capita (PPS) and an ongoing transition to renewable energy. The high internal variation (2.5) suggests that although these countries are clustered together, there are important differences between them: high CO_2 emissions per capita with low GDP per capita (PPS), such as Bulgaria, and low CO_2 emissions per capita with high GDP per capita (PPS), such as Sweden. Romania's position in this context shows both commonalities with other countries at a low level of development and opportunities to learn from successful models of advanced countries. On the other hand, Cluster 1 includes countries with high (e.g., Ireland) and low (e.g., Poland and Slovakia) GDP per capita (PPS), yet with similar renewable energy shares.

Therefore, the cluster analysis demonstrates that simple geographical or economic proximity does not guarantee a uniform trajectory, placing Romania at an inflection point where capitalizing on successful models from advanced economies could represent a starting point for overcoming productivity and sustainability gaps.

4. Discussion

The results highlight the complexity of the relationships between economic development, environmental sustainability, and the available labor force in the total population in some EU countries. The analysis shows that countries differ considerably in the way they link economic growth to environmental objectives, highlighting the multidimensional nature of sustainable development. These findings support the theoretical perspective presented in the literature review, which holds that sustainability is not limited to environmental protection but also depends on economic performance, institutional capacity, and the availability of human resources. The results partially confirm the first research hypothesis (H1), which assumed that there are significant differences in environmental sustainability between highly developed and less developed countries. The clustering shows that developed countries generally have different environmental and energy profiles compared to less developed economies. However, the relationship is not linear. Countries such as Luxembourg and Germany continue to record relatively high levels of CO_2 emissions and energy consumption, despite their high economic performance. In contrast, many countries with low levels of economic development have low CO_2 emission levels. These results are consistent with the EKC literature, which suggests that economic growth alone does not guarantee sustainability and that policy implementation, technological innovation, and the energy structure play important roles in the success of the transition to a green economy. The second research hypothesis (H2) is largely supported by the empirical results. Countries with a strong orientation toward renewable energy sources and low environmental pressures tend to form distinct clusters, whereas those that remain more dependent on conventional energy systems do not. Recent studies emphasize that the green transition represents a structural transformation of economic and energy systems, rather than a simple process of reducing emissions. The analysis indicates that the different development of renewable energy sources contributes to the formation of clusters between countries, highlighting the importance of energy transition policies in shaping sustainability trajectories at the EU level. Although the share of the working-age population in the total population was not the dominant variable in the clustering process, it remains relevant in terms of long-term sustainability. Countries facing demographic decline and, consequently, a shrinking workforce may face additional challenges in supporting investment, technological adaptation, and the workforce requirements associated with the green transition. This is the case for Romania, where demographic decline and labor migration continue to influence labor market conditions and long-term development prospects.

Romania occupies an intermediate position in the European landscape. The country benefits from relatively low levels of CO_2 emissions compared to several underdeveloped economies and has made progress in expanding the use of renewable energy. However, the lower emissions rather reflect both lower levels of industrial activity and lower energy consumption. At the same time, demographic pressure and structural economic constraints may limit the potential of countries to accelerate investments in sustainable technologies and green infrastructure. Achieving climate neutrality will therefore require not only environmental measures but also policies that address workforce sustainability, economic competitiveness, and regional development disparities. Overall, this suggests that the success of the green transition depends on the interaction between economic development, environmental policy, energy system transformation and, last but not least, demographic resilience. Countries can therefore achieve similar environmental outcomes through different development trajectories, demonstrating that sustainability is a multidimensional process shaped by economic, social and institutional factors.

5. Conclusion

This study examined Romania's position within the EU in relation to demographic change and the transition to a green economy, using a comparative analysis of selected EU member states and AHC. The results reveal significant differences between countries in economic development, energy consumption patterns, renewable energy adoption, and environmental performance.

The analysis confirms that higher levels of economic development do not necessarily reflect better sustainability outcomes. While several highly developed countries continue to experience high CO_2 emissions and substantial energy consumption, others have successfully combined economic growth with environmental protection through sustained investment in renewable energy and effective climate policies. The clustering results identified three distinct groups of countries, with Romania belonging to a cluster characterized by moderate economic performance, relatively low emissions, and a continuous transition toward greener energy systems.

Romania's position reflects both opportunities and vulnerabilities. On the one hand, the country benefits from relatively low CO_2 emissions and a growing share of renewable energy. On the other hand, demographic decline, population aging, and labor migration represent structural challenges that may reduce the capacity to sustain long-term economic growth and finance the green transition. Therefore, environmental sustainability cannot be analyzed independently of demographic and labor market developments.

The main contribution of this study is the integration of economic, environmental, and demographic dimensions in a relatively new comparative framework. The results indicate that achieving a successful green transition requires not only environmental policies but also measures aimed at strengthening demographic resilience, increasing labor force participation, and supporting sustainable economic development. For Romania, the transition to a green economy will depend on how it can simultaneously address energy, economic, and demographic challenges, particularly from a labor force perspective, while aligning with the long-term sustainability objectives of the EU.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Both authors contributed equally to the conception, analysis, and writing of this manuscript.

Availability of data

The data used in this study were collected from the EUROSTAT and Our World in Data available at https://ec.europa.eu/eurostat/web/main/data/database and https://ourworldindata.org/explorers.

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