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Economic Growth and Environmental Sustainability in Romania: The Role of Renewable Energy and Carbon Emissions

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Abstract

Carbon emissions constitute one of the most urgent environmental challenges of the 21st century. This study investigates the relationship between economic growth and carbon emissions in Romania, an emerging economy in Eastern Europe. Drawing on annual time series data from 1991 to 2024, the analysis explores how carbon emissions are influenced by key factors such as GDP growth and renewable energy consumption. To examine the long-term interactions among these variables, the Autoregressive Distributed Lag (ARDL) Bounds testing approach for co-integration was employed. The empirical results reveal a significant long-run relationship among the variables. Specifically, economic growth exerts a statistically significant positive impact on carbon emissions, highlighting the environmental cost of Romania's economic expansion. In contrast, renewable energy consumption demonstrates a statistically significant negative impact on carbon emissions, which shows that with the increase in the renewable energy consumption the carbon emissions would decrease considerably in Romania. This study contributes to the literature by providing one of the few country-specific ARDL co-integration analyses of Romania over the post-transition period (1992–2024), simultaneously examining the long-run effects of economic growth and renewable energy consumption on carbon emissions to generate evidence tailored to Romania's sustainable development pathway. These findings carry important policy implications like achieving a sustainable balance between economic development and environmental protection. It is imperative to enhance investment in and the adoption of renewable energy technologies; also there is need of decarbonizing transport through using green transport or reducing fossil fuel use in residential heating in Romania.

Keywords: economic growth, carbon emissions, renewable energy, environmental sustainability, Romania.

1. Introduction

Since 2007 when Romania joined the European Union (EU), it has been going through many steps during its economic growth (ECG), energy transformation, and environmental concerns. The relationship between economic development, renewable energy (REN) uptake, technological advancement, energy conservation measures, and carbon (CO2) emissions cut has been deemed more relevant than ever for the country to achieve sustainable development and meet EU climate targets (Diaconu et al., 2009). The country has enjoyed an improved and growing economy within the last few years, with a GDP of 4.1% in 2019 and a recovery of 5.9% in 2021 after the COVID-19 pandemic (World Bank, 2023). However, this growth has been linked with notable energy production and utilization of pollution emissions particularly in Romania because of the utilization of fossil energies and energy-demanding sectors (Colesca & Ciocoiu, 2013). The development of REN sources has accelerated in Romania, the share of which in the gross final energy use was 24.29% in 2020, which exceeded the 2020 target of 24% (Eurostat, 2022b).

This advancement has been made by policies, technology and enhanced participation of the private sector. At the same time, measures for increasing energy efficiency (ENEF) have been taken in the building, industry, as well as transport sectors in accordance with Romania's National Energy Efficiency Action Plan (NECP, 2019). Although Romania has achieved some success in the REN promotion and has continued to enjoy stable economic prosperity, the country still has a lot to do for balancing its ECG and sustainable energy and emission objectives. ECG, REN, technological advancements, efficiency, and CO2 emissions form a system that is neither simple to analyze nor to address (Pacesila et al., 2016). Nevertheless, Romania, which achieved its 2020 target early, still has a highly dependent energy structure based on coal and natural gas (Dusmanescu et al., 2014). This dependency makes the country emit a lot of CO2 while at the same time making the country vulnerable to energy insecurity and price fluctuations in the international fossil fuel markets. Besides, according to (Cioca et al., 2015), Romania still ranks among the EU leaders by energy intensity, which proves the ineffective energy consumption in the economy branches. The country's technology innovation index, which is important for advancing ENEF and REN options, is lower than the EU average in R&D spending and clean energy technological patents.

Moreover, the shift to a low-carbon economy presents social and economic impacts, most especially in the fossil fuel-reliant economies, which require a just transition. The situation is also exacerbated by policy incoherencies, regulatory impediments, as well as lack of funding for clean energy ventures that slow down the quick ramp-up of REN/ENEF (Zamfir et al., 2016). Thus, this study seeks to meet the urgent need to understand the dynamic interrelations between the discussed factors – ECG, REN uptake, technological advancement, ENEF, and CO2 emissions within Romania. Through these relations, the research aims to determine the main options for policy actions and investment that can support the enhancement of the efficiency of Romania's transformation towards a sustainable, low-carbon economy and maintain the high rate of economic development. The examination of the interconnection between the ECG, REN use, and CO2 emissions in Romania is rather strong and fluctuating. To date, Romania has experienced its economic development hand in hand with the increase in energy use and therefore higher emissions of CO2, as described in the Environmental Kuznets Curve (EKC) hypothesis.

Nevertheless, the trends indicate that there is a possibility of ECG being detached from CO2 emissions mainly due to the REN growth in the country's energy generation (Marinescu, 2020). The gross domestic product (GDP) of Romania has been increasing continuously after Romania's accession to the EU, with a compound annual growth rate of 3.9% in the period between 2007 and 2019 (World Bank, 2024). The increase in renewable energy has helped to decrease the carbon intensity of the economy as well as CO2 emissions per unit of GDP between the period of 2007 and 2019 (Ciobotea et al., 2024). Yet, (Soava & Mehedintu, 2023) noted that in the case of Romania, the correlation between ECG and CO2 emissions is not a direct one; there may be intervals of accelerated growth that cause short-term growth in emissions. The contribution of REN in the reduction of this impact cannot be overemphasized, (Papież et al., 2018) revealed a strong negative relationship between REN consumption and CO2 emissions in Central and Eastern European Countries including Romania. Nevertheless, there are difficulties in the complete utilization of REN in mitigating emissions from economic development. (Apergis & Ozturk, 2015) Argued that the potential of REN in emissions mitigation is subject to other conditions including ENEF improvement, technological advancement and enabling policies. As a result, though REN can greatly contribute to managing the CO2 footprint of Romania's economic development, only an integrated approach to the decarbonization process is likely to be effective.

Therefore, responding to these challenges with industry-specific interventions and encouraging technological adaptation for minimal CO2 emission is critical for the fate of Romania's CO2 emission profile. This paper aims to estimate the degree of economic growth influence on carbon emissions while there is a possibility of direct relation because of rising industries and inverse relation due to better technologies. This paper will discuss the manners in which integration of renewable power determines emission decrease with reference to the offset impact on fossil fuel utilization. While many studies focus on broader regional or cross-country analyses, they often overlook Romania's unique economic and energy transformation. Moreover, insufficient attention has been given to simultaneously assessing the effects of economic growth and renewable energy adoption on carbon emissions using robust co-integration techniques such as the ARDL Bounds testing approach. Hence, it is proposed that through the analysis of these various factors interacting with each other, this study's goal is to understand policy intervention and investment points. Thus, the research objectives include first, understanding each of these variables and second, how these variables combine to affect Romania's CO2 emissions trajectory and third, the improvement of policy-making that sufficiently addresses the growth and development of the Romanian economy and the reduction of CO2 emissions in the country.

2. Literature Review

This section covers the review of existing literature regarding the influence of economic expansion on CO2 emissions. The specific influence of each variable on emissions has been discussed. As per the literature, it has been well written that ECG and CO2 emissions went hand in hand in the past, but there are signs that couplings are possible through technological changes, policy influencing, and changes towards renewable sources. Economic development previously had been associated with the emission of CO2 since various domestic and industrial activities consume energy. The fact that ECG is associated with the growth of CO2 emissions is affirmed in several research studies. Therefore, (Gbadeyan et al., 2024) call for a mechanism to decouple economic activities from CO2 emissions growth with the aim of attaining a zero-carbon economy. For developing countries, (Khan & Rahmat, 2024) established that ECG significantly results in the emission of CO2 as such countries aim at industrialization and energy usage to spur their growth. This trend is further by the political and institutional conditions that may not be oriented towards the protection of the environment. Implying that the experience of ECG means increased emissions, and then – reduced emissions when the economy has matured and begun to use cleaner technologies – proposed by the EKC hypothesis. This hypothesis is true in the framework of various African and emerging countries where economic development first causes emissions to go high and then decline as advanced and cleaner technologies are adopted (Hunjra et al., 2024; Teklie & Yağmur, 2024).

Keeping ECG and CO2 emissions separate is a key approach to sustainable development. It refers to changes to the low-carbon energy systems as well as the adoption of innovative technologies that would reduce the CO2 footprints without hindering economic progress (Gbadeyan et al., 2024). This transition depends upon the role of REN. In their research study, (Topa, 2024) illustrates the potency of resorting to renewable energy in allowing for the development of the economy while lessening the emission of CO2 gaseous components in countries which consume more REN. Similarly, (Kayani et al., 2023; Khan & Rahmat, 2024) mentioned that technological progression and energy mix diversification are important to decouple ECG from CO2 emissions. In addition, policy and governance interventions that manage the tradeoff between ECG and CO2 emissions are important. Environmental quality and emissions can be improved through devotion to the rule of law, political stability and anti-corruption measures (Khan & Rahmat, 2024). Further, green financing, sustainable practices and the use of REN are also needed to scale down CO2 emissions whilst helping with the progress of ECG. Both (Teklie & Yağmur, 2024) and (Aydin, 2023) show how such policies can aid countries shift toward cleaner sources of energy and while minimizing the use of traditional fossil fuel energy. While decoupling is possible, multiple challenges exist that is, how to align the growth of the economy with the preservation of the environment. In many regions, the positive correlation between ECG and CO2 emissions continues (Choudhury et al., 2023; Ray et al., 2023), therefore, context-specific strategies and policies are necessary.

One of the focused areas of this research is identifying the influence of REN on CO2 emissions, considering the need to eliminate climate change (Sohaib et al., 2025; Yang et al., 2026). With rising amounts of CO2 released into the atmosphere, fossil fuel consumption being the driver, REN sources are increasingly being viewed as a means by which to cut CO2 emissions. A recent study has shown that REN policies have reduced emissions of CO2 throughout the globe. Drawing on the most recent research reported by (Saqib, 2024), regulatory, economic, and R&D policies that promote REN add to the effectiveness of the REN in curbing CO2 emissions. The relationship between REN investment and CO2 emissions is complicated (Appiah-Otoo et al., 2023). Even though investments in REN at first encourage higher emissions because of low substitution rates of fossil fuels, solar and wind investments in emissions gradually but substantially deplete emissions beyond some threshold investment. However, the contribution of ECG mechanisms is still present because renewable investment in energy contributes to greening the economy and thus indirectly reducing CO2 emissions (Appiah-Otoo et al., 2023). Green energy has a different impact on CO2 emissions by region and by sector. In China, (Wang et al., 2023) show that the consumption of REN has helped CO2 emissions by reducing both total and regional emissions and suggest that trade openness and ECG have impacts on emissions.

Similarly, (Mukhtarov et al., 2022) find that REN consumption reduces CO2 emissions in oil-rich economies, showing that green energy could cancel out the carbon footprint of fossil fuel-reliant economies. Also, green energy technologies have the ability on a global scale to eliminate CO2 emissions from electricity generation in the coming decades and drive down the impacts of global warming (Lima et al., 2020). Progress is being made in the development of REN by emerging as well as developed economies such as the US, China, Germany, and India: all of these countries are making commitments to clean up the global climate by reducing emissions (Lima et al., 2020). Nonetheless, CO2 emissions are highly influenced by the integration of REN (as discussed above) and environmental technologies. (Bozkaya et al., 2024) further proves that a bidirectional causal relation exists between CO2 emissions and REN consumption, such that these technologies are able to reduce emissions. Recently, (Wu et al., 2023) further added that green technology innovation reduces the amount of CO2 emission by increasing the efficiency and cleanliness in economically developed regions with strong scientific and technical resources. The rising level of CO2 emissions is alarming for the development as well as the sustainability of the country; therefore, it is the need of the hour to curb climate change issues and achieve SDGs. Decreasing energy consumption in a broad range of sectors can result in substantial ENEF and, as a result, reductions in CO_2 emissions.

The synthesis of the literature identifies key areas for further research which delves further into understanding and influencing policy making. Studies across varying regions tend to link ECG to rising CO_2 emissions. An example is that BRICS countries suffer from a direct relationship between CO_2 emissions and economic development (Zhang et al., 2024), indicating the environmental consequences of growth. A similar situation is observed in China when a 1% increase in ECG leads to a 0.51% rise in CO_2 emissions (Ahmad et al., 2024). Likewise, CO_2 emissions do grow with ECG in Bangladesh, as a 1% rise in growth is associated with a 1.3% rise in emissions (Raihan et al., 2022). The relationship is not uniform however in all contexts. The correlation between ECG and CO_2 emissions is different across the G7 economies and depends on the country, it is economically important in Western countries such as the USA and Germany, but not as much in the south of Europe and Japan (Liu & Rasheed, 2023). Such a finding implies the necessity for more granular studies that account for economic growth–emissions nexus.

In general, REN is thought to decrease CO_2 emissions. Specifically, a percentage increase in the use of REN in China is associated with a reduction of 0.03% in CO_2 (Ahmad et al., 2024). In Bangladesh, CO_2 emissions dropped by 0.15% with the increase in the percentage of REN utilized by 1% (Raihan et al., 2022). The complex interactions between REN and CO_2 emissions and between REN and environmental technology are highlighted by bidirectional causality (Bozkaya et al., 2024). However, more research is needed to know when REN can best cut emissions. Reducing emissions is important but, wedded with an expected focus on economic growth and renewable energy, the literature often fails to consider the crucial importance of all these factors simultaneously in the context of Romania, which is an emerging nation and has a significant role in the development of sustained ECG. Hence, this study covers all these limitations and gaps to contribute to the existing knowledge strand regarding environmental sustainability.

3. Data and Methodology

3.1 Data and Variables

We extracted data for our variables; carbon emissions, GDP growth, renewable energy consumption, trade and consumption expenditure from the World Development Indicators. The dataset comprises annual time series data from 1992 to 2024, with further descriptions provided in Table 1.

Table 1: Data and Variables Description

Variables	Symbols	Description & Measurement Scale	Data Source
Carbon Emissions	CO2	Carbon dioxide (CO2) emissions excluding LULUCF per capita.	WDI, 2026.
GDP Growth	GDP	GDP growth (annual %).	WDI, 2026.
Renewable Energy Consumption	REW	Renewable energy consumption (% of total final energy consumption).	WDI, 2026.
Trade Openness	TRD	Trade (% of GDP)	WDI, 2026.
Consumption Expenditure	CON	Final consumption expenditure (% of GDP)	WDI, 2026.

3.2. Econometric Model

The primary objective of this study is to examine the impact of GDP growth and renewable energy consumption on carbon emissions of Romania. Theoretically, GDP is positively correlated with CO2 emissions (Kasperowicz, 2015; Gonzalez-Alvarez & Montanes, 2023; Ameyaw & Yao, 2018), while renewable energy consumption has a negative effect on CO2 emissions (Mukhtarov et al., 2022). Accordingly, our model with CO2 as a dependent variable and GDP growth, renewable energy consumption, trade and consumption expenditure as independent variables is shared below.

$$CO2_t = (GDP_t, REW_t, TRD_t, CON_t) \quad \textbf{(1)}$$

The general model to be estimated is shared below

$$CO2_t = b_0 + b_1GDP_t + b_2REW_t + b_3TRD_t + b_4 CON_t + e_t \quad \textbf{(2)}$$

where:

CO2 = C02 Emissions

GDP = GDP growth (annual %)

REW = Renewable Energy Consumption

TRD = Trade (% of GDP)

CON = Consumption Expenditure (% of GDP)

t = time from 1992 – 2024 et = error term

For an ARDL model, the dynamic specification of equation can be written as:

$$CO2_t = \beta_0 + \sum_{i=1}^{p} \phi_i CO2_{t-i} + \sum_{j=0}^{q_1} \beta_{1j} GDP_{t-j} + \sum_{k=0}^{q_2} \beta_{2k} REW_{t-k} + \sum_{l=0}^{q_3} \beta_{3l} TRD_{t-l} + \sum_{m=0}^{q_4} \beta_{4m} CON_{t-m} + \varepsilon_t \quad \textbf{(3)}$$

where:

$CO2_t$= Carbon dioxide emissions (dependent variable)

GDP_t= Gross Domestic Product

REW_t= Renewable Energy Consumption

TRD_t= Trade Openness (Trade)

CON_t= Consumption Expenditure

β_0= Intercept

ϕ_i= Coefficients of lagged dependent variable

$\beta_{1j}, \beta_{2k}, \beta_{3l}, \beta_{4m}$= Short-run coefficients of explanatory variables

ε_t= Error term

In case of ARDL(1,1,1,1,1) the model would be as below

$$CO2_t = \beta_0 + \phi_1 CO2_{t-1} + \beta_{10} GDP_t + \beta_{11} GDP_{t-1} + \beta_{20} REW_t + \beta_{21} REW_{t-1} + \beta_{30} TRD_t + \beta_{31} TRD_{t-1} + \beta_{40} CON_t + \beta_{41} CON_{t-1} + \varepsilon_t \quad \textbf{(4)}$$

The short-run Error Correction Model (ECM) is estimated as below

$$\Delta CO2_t = \alpha_0 + \sum_{i=1}^{p-1} \alpha_{1i}\,\Delta CO2_{t-i} + \sum_{j=0}^{q_1-1} \alpha_{2j}\,\Delta GDP_{t-j} + \sum_{k=0}^{q_2-1} \alpha_{3k}\,\Delta REW_{t-k} + \sum_{l=0}^{q_3-1} \alpha_{4l}\,\Delta TRD_{t-l} + \sum_{m=0}^{q_4-1} \alpha_{5m}\,\Delta CON_{t-l} + \psi ECT_{t-1} + u_t \quad \textbf{(5)}$$

where:

$$ECT_{t-1} = CO2_{t-1} - \hat{\beta}_0 - \hat{\beta}_1 GDP_{t-1} - \hat{\beta}_2 REW_{t-1} - \hat{\beta}_3 TRD_{t-1} - \hat{\beta}_4 CON_{t-1}$$

and:

$ECT_{t-1}$is the error correction term.

$\psi$is the speed of adjustment coefficient, expected to be negative and statistically significant.

A value of $\psi = -0.60$, for example, indicates that 60% of the disequilibrium is corrected each period.

4. Empirical Results and Discussion

4.1 Descriptive Statistics

As a preliminary step, we performed a statistical analysis of the variables as listed in Table 2. The analysis includes the descriptive statistics and the Jarque–Bera normality test to assess the distributional properties of the variables, the data is normally distributed without outliers or the missing values.

Table 2: Summary Statistics for the Selected Variables

Variables	Mean	Median	Standard Deviation	Jarque-Bera	Skewness	Kurtosis
CO2	4.646116	4.369012	0.700464	2.993418	0.627391	2.223757
GDP	3.298860	4.083148	4.595618	1.401140	-0.498495	2.841816
REW	18.16212	18.35000	5.386123	3.532957	-0.794655	2.791393
TRD	68.91651	63.99025	13.60877	2.935119	0.197106	1.593150
CON	81.07060	79.86227	3.959868	1.852695	0.428932	2.218025

The Jarque–Bera probabilities for CO2 (0.2239), GDP (0.4963), REN (0.1709), TRD (0.2305), and CON (0.3960) were all greater than the 5% significance level, indicating that all variables are approximately normally distributed. Furthermore, skewness values are also within acceptable limits (±1), while kurtosis values were close to the benchmark value of 3, confirming the absence of severe departures from normality.

4.2. Augmented Dicky Fuller (ADF) Unit Root Test

To assess the stationary of the variables, we applied the Augmented Dickey-Fuller (ADF) unit root test, following Dickey & Fuller (1979). Ensuring stationary is crucial for applying the ARDL Bounds test, as it confirms that none of the variables are integrated at the second order, I(2). Our ADF test results indicate that the variables are stationary at levels I(0) and I(1), as shown below in Table 3.

Table 3: ADF Unit Root Test for Stationary

Variable	Symbol	Level	1st Difference
Carbon Emissions	CO2	Non-Stationary	Stationary (Prob: 0.0009)
GDP Growth	GDP	Stationary (Prob: 0.0005)	N/A
Renewable Energy Consumption	REW	Non-Stationary	Stationary (Prob: 0.0019)
Trade Openness	TRD	Non-Stationary	Stationary (Prob: 0.0000)
Consumption Expenditure	CON	Non-Stationary	Stationary (Prob: 0.0179)

4.3. ARDL Bounds Test

The ARDL Bounds test was then employed to estimate the long-run relationship between variables in the model, effectively addressing the issue of spurious regression. Traditional time series tests, such as those by Engle and Granger (1987) and Johansen (1988), were suitable only when variables were integrated at the same order. However, these tests were insufficient for variables with mixed orders of integration, leading to the development of the ARDL co-integration model by Pesaran et al. (2001). A long-run relationship is confirmed if the F-statistics exceed the upper bound value; if it falls below the lower bound, there is no co-integration, and if it lies between the bounds, the result is inconclusive. As indicated in Table 4, the F-statistics have surpassed both the lower and upper bounds, confirming the presence of co-integration in our model.

Table 4: ARDL Bounds Test Results

Test Statistics	Value	K
F-statistic	6.857423	4
Critical Value Bounds		
Significance level	I (0)	I (1)
10%	2.525	3.560
5%	3.058	4.223
1%	4.280	5.840

4.4. ARDL Long-run Estimates

The ARDL long-run estimates in table 5 below reveal that economic growth significantly increases carbon emissions in the long run, indicating that expansion of economic activity contributes to environmental degradation. Specifically, a one-unit increase in GDP increases CO_2 emissions by approximately 0.038 units in the long run. Renewable energy consumption exhibits a negative relationship with CO_2 emissions, suggesting that greater adoption of renewable energy helps mitigate environmental pollution, although the effect is only significant at the 10% level. A one-unit increase in renewable energy consumption reduces CO_2 emissions by approximately 0.026 units. Trade openness and consumption do not exert statistically significant effects on carbon emissions.

Table 5: ARDL Long-run Estimate Results

Variable	Coefficient	Standard Error	t-statistics	P-value
GDP	0.037952	0.009919	3.826110	0.0008
REW	-0.026260	0.013453	-1.952037	0.0622
TRD	-0.004319	0.005151	-0.838440	0.4097
CON	-0.007614	0.012055	-0.631545	0.5334

Note: Dependent variable = CO2 & Independent variables = GDP, REW, TRD, CON.

The error correction model reveals a statistically significant and negative error correction term (ECT = -0.2988, $p < 0.01$), confirming the existence of a stable long-run relationship among carbon emissions, economic growth, renewable energy consumption, trade openness, and consumption. The magnitude of the coefficient indicates that approximately 29.9% of any short-run disequilibrium is corrected annually, suggesting a moderate speed of adjustment toward long-run equilibrium.

4.5 Stability Diagnostic Tests

We used various diagnostic tests like Breusch–Godfrey Serial Correlation LM Test, Heteroskedasticity Test (Breusch–Pagan–Godfrey) & Cumulative & Cumulative Sum of Squares of Recursive Residuals to check the consistency of the estimated model.

4.5.1 Breusch–Godfrey Serial Correlation LM Test

We used Breusch–Godfrey Serial Correlation LM test to detect the presence of serial correlation (autocorrelation) in the residuals of a regression model. The null and alternative hypothesis are shared below

Null hypothesis (H_0): No serial correlation

Alternative hypothesis (H_1): Serial correlation exists

Table 6: Breusch–Godfrey Serial Correlation LM Test Results

Test Statistic	Value	Probability
F-statistic	2.417479	0.1114
Obs*R-squared	5.558429	0.0621

Since both Prob(F-statistic) & Prob (Obs*R-squared) are greater than 0.05, so we failed to reject Null hypothesis which means there is no evidence of serial correlation.

4.5.2 Heteroskedasticity Test (Breusch–Pagan–Godfrey)

We use Breusch–Pagan–Godfrey test to determine that whether the variance of the residuals in a regression model is constant or not. The null and alternative hypothesis are shared below

Null hypothesis (H_0): Homoskedasticity (constant variance of errors)
Alternative hypothesis (H_1): Heteroskedasticity (non-constant variance)

Table 7: Heteroskedasticity Test Results

Test Statistic	Value	Probability
F-statistic	1.702308	0.1620
Obs*R-squared	9.281663	0.1583
Scaled explained SS	5.444875	0.4881

Since all these values Prob(F-statistic), Prob (Obs*R-squared) & Prob (Scaled explained SS) are higher than 0.05, so we failed to reject null hypothesis which means there is no evidence of heteroskedasticity in our model.

4.5.3 Cumulative & Cumulative Sum of Squares of Recursive Residuals

To assess the stability of the long-run coefficients, we conducted the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests of recursive residuals, as described by Brown, Durbin & Evans (1975). Figure 1 and Figure 2, the plots of both the

CUSUM and CUSUMSQ statistics remain completely within the critical boundaries at the 5% significance level.

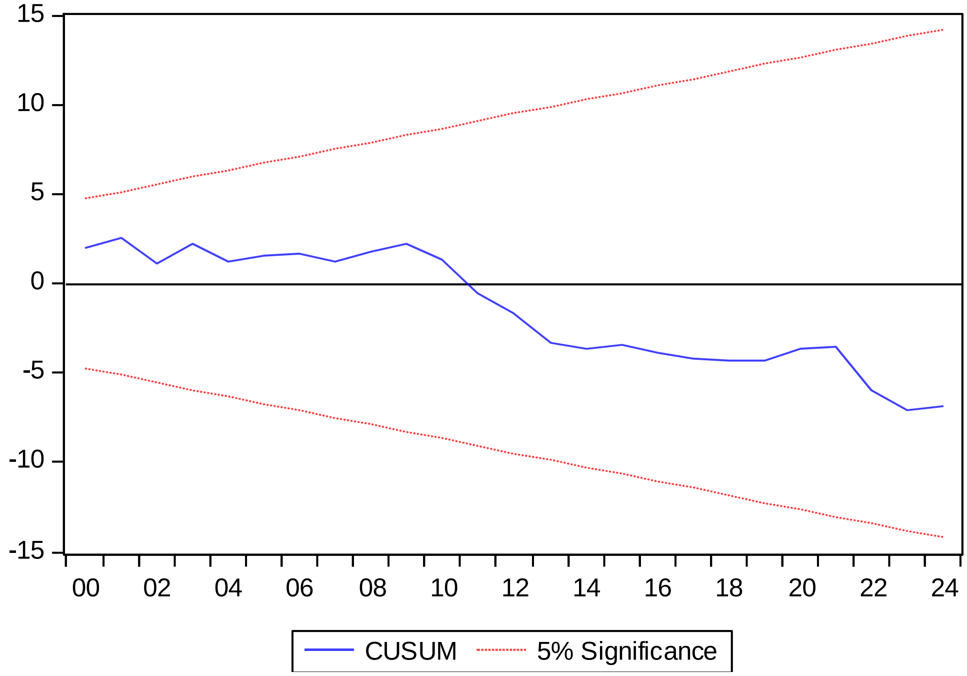

Figure 1: Cumulative Sum of Recursive Residuals

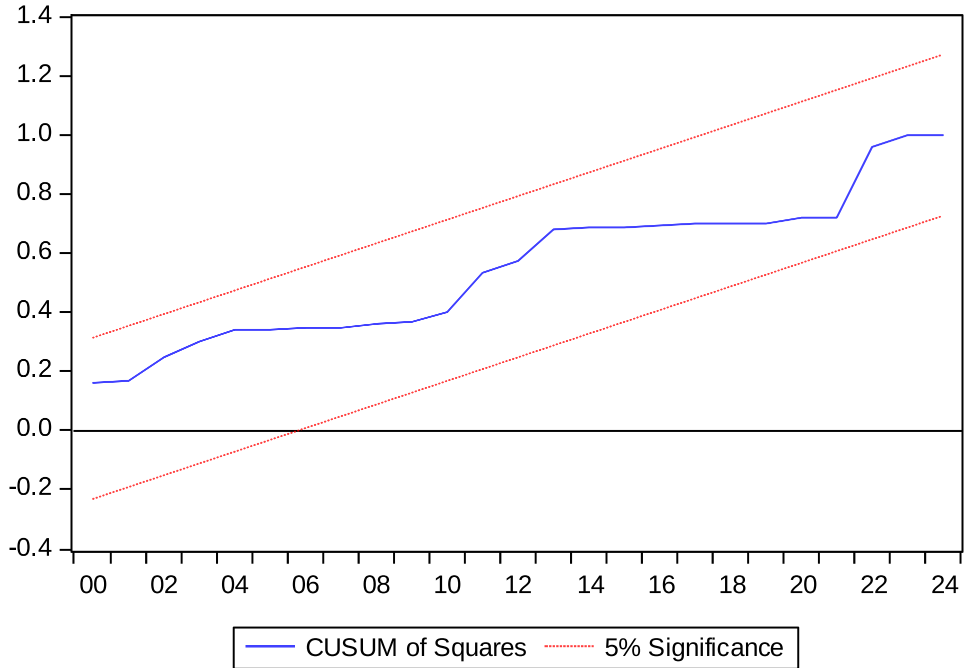

Figure 2: Cumulative Sum of Squares of Recursive Residuals

5. Conclusion and Recommendations

We evaluated the effects of economic growth and renewable energy consumption on carbon emissions in Romania. Our analysis, using the ARDL-bound testing approach, revealed a significant long-run relationship between the variables in our model. Specifically, GDP has a significant positive effect on CO2 emissions, while renewable energy consumption has a significant negative impact on CO2 emissions. We recommend that Romania prioritize the adoption of clean and environmentally friendly technologies to support sustainable development. To reduce reliance on fossil fuels and encourage green growth, subsidies should be provided for renewable energy consumption. Investors should be incentivized to fund research focused on developing clean technologies. Additionally, raising public awareness and education about the benefits of renewable energy is crucial for increasing its adoption. By following this approach, Romania can cultivate an informed and engaged society, thereby accelerating its transition toward a greener and more sustainable future. Preferential treatment should also be given to investors who adopt green technologies and sustainable production methods. Furthermore, advanced EU economies should share their technological expertise to help Romania and other Eastern European countries to develop high-quality, cost-effective clean technologies.

5.1 Policy & Practical Implications

The findings of this study have important implications for policymakers, investors, and other stakeholders in Romania. The positive relationship between economic growth and CO_2 emissions suggests that the country's economic expansion continues to rely, at least partly, on carbon-intensive activities. Therefore, economic development strategies should be designed in a way that decouples growth from environmental degradation. The negative effect of renewable energy consumption on CO_2 emissions highlights the critical role of renewable energy in supporting Romania's transition toward a low-carbon economy. This finding supports the Romanian government's objective of increasing the share of renewable energy in the national energy mix to approximately 31% by 2030 and achieving carbon neutrality by 2050.

5.2 Limitations & Future Directions

This study is limited by the availability of data, which extends only up to 2024. As a result, more recent developments could not be incorporated into the analysis, which may affect the timeliness of the findings. Furthermore, future research could extend this work by conducting a panel analysis involving a group of Eastern European countries. Such an approach would allow for cross-country comparisons and a more comprehensive understanding of regional patterns and differences over time.

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Declaration of AI Use

The authors confirm that no AI tools were used for data collection, statistical analysis, interpretation of results, or development of the study's scientific content.

Data Availability

The datasets are available from the corresponding author upon reasonable request.

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