RENEWABLE ENERGY CONSUMPTION AND ECONOMIC GROWTH IN ROMANIA: EVIDENCE FROM A TIME-SERIES ECONOMETRIC ANALYSIS

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Abstract: *This study investigates the relationship between renewable energy consumption, economic growth and environmental factors in Romania over the period 1990–2022. Using annual data and a time-series econometric framework, the analysis examines the long-run and short-run dynamics between gross domestic product (GDP), renewable energy consumption, carbon dioxide (CO_2) emissions, energy use, gross capital formation and trade openness. The Autoregressive Distributed Lag model approach is employed to explore cointegration relationships among the variables. The empirical results reveal the existence of a long-run equilibrium relationship between economic growth and the selected explanatory variables. Renewable energy consumption is found to have a positive but statistically insignificant impact on economic growth, suggesting that its contribution remains limited in the Romanian context. At the same time, CO_2 emissions and energy use are positively associated with economic growth, indicating that Romania's economic expansion is still partially dependent on conventional energy sources. Gross capital formation plays a significant role, particularly in the short run. The short-run dynamics confirm the adjustment towards long-run equilibrium, while causality analysis highlights the directional relationships between the variables. Overall, the findings emphasize the need to strengthen renewable energy policies to support sustainable economic growth.*

Keywords: *renewable energy; economic growth; CO2 emissions; ARDL; Romania; energy consumption*

JEL Classification: *Q42; Q43; C32; O44*

1. Literature review

The relationship between economic growth, energy consumption and environmental sustainability has been extensively analyzed in academic literature. In recent decades, increasing attention has been given to the role of renewable energy in promoting sustainable development and reducing environmental degradation.

A substantial body of research has explored the nexus between renewable energy consumption and economic growth. Early contributions by Apergis and Payne (2010) provide evidence of bidirectional causality between renewable energy consumption and economic growth in OECD countries, suggesting a mutually

reinforcing relationship. Similarly, Shahbaz et al. (2012) highlight the positive role of renewable energy in supporting economic growth in developing economies.

Further studies confirm these findings across different regions and methodologies. For instance, Ozturk (2010) emphasizes the importance of energy consumption in economic growth, while Salahuddin and Gow (2014) show that renewable energy contributes to long-term economic expansion in emerging economies. In addition, Al-Mulali et al. (2013) demonstrate that renewable energy reduces environmental degradation while supporting growth.

Another strand of the literature focuses on the environmental consequences of economic growth. The Environmental Kuznets Curve (EKC) hypothesis suggests that environmental degradation initially increases with economic growth and later decreases as income levels rise. This hypothesis has been extensively examined by Stern (2004) and Grossman and Krueger (1995), who provide evidence of non-linear relationships between income and environmental quality.

Recent empirical studies have further investigated the energy–growth–environment nexus using advanced econometric techniques. For example, Shahbaz et al. (2015) and Doğan and Seker (2016) examine the role of renewable energy and trade openness in reducing CO_2 emissions. Their results indicate that renewable energy contributes to environmental sustainability, although its impact on economic growth varies across countries.

In the context of European and transition economies, the relationship between renewable energy, economic growth and environmental indicators is shaped by structural reforms and policy changes. Studies focusing on Eastern European countries, such as Destek (2016), highlight the importance of renewable energy in mitigating environmental degradation, while also emphasizing the heterogeneity across countries.

Moreover, trade openness has been identified as an important factor influencing both economic growth and environmental quality. Frankel and Rose (2005) argue that trade can have both positive and negative environmental effects, depending on the regulatory framework and level of development. Similarly, Halicioglu (2009) finds that trade openness significantly affects CO_2 emissions in developing countries.

Despite the extensive literature, panel data approaches dominate most empirical studies, potentially masking country-specific dynamics. As noted by Pesaran et al. (2001), time-series analyses provide a more detailed understanding of long-run and short-run relationships within individual countries. Therefore, country-specific studies are essential to capture the unique characteristics of national economies.

In the case of Romania, relatively few studies have examined the energy–growth–environment nexus using time-series methods. Given the country's transition from a centrally planned economy to a market-based system and its integration into the European Union, the dynamics between renewable energy, economic growth and environmental indicators are likely to differ from those observed in other regions.

Building on previous findings, the present study focuses on Romania and applies a time-series econometric framework to investigate the relationship between renewable energy consumption, economic growth, CO_2 emissions and other macroeconomic variables. By doing so, the study contributes to the literature by providing country-specific evidence for a transition economy undergoing structural and environmental transformations.

2. Romanian national and regional context

Romania represents an interesting case study in this regard. Over the past three decades, the Romanian economy has undergone profound structural changes associated with the transition from a centrally planned economy to a market-based system, accompanied by integration into the European Union and the adoption of EU energy and environmental policies. These transformations have significantly affected the country's energy consumption patterns, the development of renewable energy sources, and the evolution of carbon emissions.

Given these developments, the present study aims to investigate the relationship between economic growth, renewable energy consumption, CO_2 emissions, energy use, gross capital formation and trade openness in Romania over the period 1990–2022. Using a time-series econometric framework, the paper seeks to identify the long-run and short-run dynamics between these variables and to contribute to the broader literature on the energy–growth–environment nexus.

The contribution of this study is twofold. First, it provides a country-specific analysis focusing on Romania, complementing previous regional studies that relied on panel data approaches. Second, by incorporating multiple economic and environmental variables within a time-series framework, the paper offers additional insights into the role of renewable energy in supporting sustainable economic development in transition economies.

3. Data and methodology

We analyze the relationship between renewable energy consumption, economic growth and environmental factors in Romania using a time-series econometric approach. This framework allows us to examine how the selected variables influence economic growth over time, capturing the dynamic interactions between energy use, environmental indicators and macroeconomic variables within a single country context.

The study is based on annual data for Romania covering the period 1990–2022. The dataset includes the following variables: gross domestic product (GDP), renewable energy consumption, carbon dioxide (CO_2) emissions, energy use, gross capital formation and trade openness. GDP is used as a proxy for economic growth, while renewable energy consumption reflects the transition towards sustainable energy sources. CO_2 emissions and energy use are included to capture environmental pressure and overall energy demand, whereas gross capital formation and trade openness are incorporated as control variables influencing economic performance.

The data was collected from the World Bank, specifically from the World Development Indicators database, which provides consistent and comparable macroeconomic and environmental statistics.

To examine the long-run and short-run relationships between the variables, we employ the Autoregressive Distributed Lag model approach. The ARDL model is particularly suitable for small sample sizes and allows for the inclusion of variables integrated of order I(0) and I(1), making it appropriate for the present analysis.

The Bounds Test proposed by Pesaran, Shin and Smith (2001) is used to investigate the existence of a cointegration relationship among the variables. Prior to this, unit root tests are performed to determine the order of integration of each variable, including the Augmented Dickey-Fuller test and the Phillips-Perron test.

To estimate the short-run dynamics and the speed of adjustment towards long-run equilibrium, an Error Correction Model (ECM) is derived from the ARDL specification. In addition, diagnostic tests are conducted to ensure the validity and robustness of the model, including tests for autocorrelation, heteroskedasticity and model stability. Finally, to explore the direction of causality between the variables, the Granger causality test is applied.

This study investigates the relationship between economic growth, renewable energy consumption and environmental factors in Romania over the period 1990–2022 using a time-series econometric framework. We will investigate two research hypotheses:

H1: Renewable energy consumption has a positive and statistically significant impact on economic growth in Romania.

H2: CO_2 emissions have a significant relationship with economic growth in Romania.

The baseline empirical model is specified as follows:

$$GDP_t = f(REN_t, CO2_t, EN_t, GCF_t, TR_t)$$

In log-linear form:

$$\ln GDP_t = \beta_0 + \beta_1 \ln REN_t + \beta_2 \ln CO2_t + \beta_3 \ln EN_t + \beta_4 \ln GCF_t + \beta_5 \ln TR_t + \varepsilon_t$$

Where:

- GDP= economic growth (GDP)
- REN= renewable energy consumption
- $CO2$= carbon dioxide emissions
- EN= energy use
- GCF= gross capital formation
- TR= trade openness

All variables are transformed into natural logarithms to reduce heteroskedasticity and interpret coefficients as elasticities.

4. Results

The empirical analysis begins with the examination of the stationarity properties of the variables. The results of the Augmented Dickey-Fuller test and Phillips-Perron test indicate that the variables are integrated of order 1, which justifies the application of the Autoregressive Distributed Lag model approach.

Table 1. Augmented Dickey-Fuller test and Phillips-Perron test

Variable	ADF Level	ADF First Diff	PP Level	PP First Diff	Order of Integration
lnGDP	-2,14	-4,05***	-2,55	-3,99***	I(1)
lnREN	-0,24	-4,67***	-0,24	-4,73***	I(1)
lnCO2	-2,00	-4,40***	-2,79	-4,50***	I(1)
lnEN	-0,24	-4,67***	-0,24	-4,73***	I(1)
lnGCF	-1,93	-4,46***	-2,1	-4,42***	I(1)
lnTR	-1,43	-5,34***	-1,48	-5,34***	I(1)

*** p<0.01, ** p<0.05, * p<0.10

Source: authors' computations in Eviews 12

The long-run coefficients reveal that most variables do not have a statistically significant impact on economic growth in Romania.

Table 2. Long-run ARDL Estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnREN	0.7163	47.358	0.1513	0.8810
lnCO2	26.697	121.240	0.2202	0.8280
lnEN	-69.675	153.080	-0.4550	0.6550
lnGCF	36.775	21.326	17.240	0.1000
lnTR	-18.134	38.597	-0.4700	0.6440
C	470.595	1.178.540	0.3990	0.6940

*** p<0.01, ** p<0.05, * p<0.10
Source: authors' computations in Eviews 12

Renewable energy consumption exhibits a positive but statistically insignificant coefficient, suggesting that its contribution to long-term economic growth remains limited. Similarly, CO_2 emissions and energy use are not statistically significant, indicating that their long-run influence on GDP is weak.
Gross capital formation shows a positive coefficient and is close to statistical significance, highlighting the importance of investment in supporting economic performance. Trade openness has a negative but statistically insignificant effect.
Overall, the long-run results suggest that investment plays a more important role than energy-related variables in explaining economic growth in Romania.

Table 3. Short-run ARDL (ECM) Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ΔlnCO2	10.618	22.983	0.4620	0.6490
ΔlnCO2(-1)	0.3951	0.7909	0.5000	0.6230
ΔlnCO2(-2)	-0.9819	0.4927	-19.940	0.0600
ΔlnEN	-12.396	24.727	-0.5010	0.6220
ΔlnGCF	**19.982**	0.6670	29.960	0.0070
ΔlnGCF(-1)	**-13.439**	0.5862	-22.930	0.0330
ΔlnREN	-24.774	18.149	-13.650	0.1870
ΔlnREN(-1)	26.049	16.206	16.070	0.1240
ΔlnTR	-0.3226	0.6147	-0.5250	0.6050
ECM(-1)	**-0.8221**	—	—	**0.0000**

*** p<0.01, ** p<0.05, * p<0.10
Source: authors' computations in Eviews 12

The short-run results indicate that gross capital formation has a strong and statistically significant impact on economic growth in Romania. The contemporaneous effect is positive, while the lagged coefficient is negative, suggesting short-term adjustment dynamics.
CO_2 emissions exhibit a weak and marginally significant effect, indicating limited short-run environmental influence on economic growth. In contrast, renewable energy consumption does not show a statistically significant impact, suggesting that its contribution to short-term economic performance remains limited.

Energy use and trade openness are also found to be statistically insignificant in the short run. Overall, the results highlight that short-term economic growth in Romania is primarily driven by investment activity rather than energy-related factors.
The error correction term (ECM(-1)) is negative and statistically significant, confirming the existence of a stable long-run equilibrium relationship among the variables.
The estimated coefficient (-0.82) indicates that approximately 82% of deviations from the long-run equilibrium are corrected within one period. This suggests a relatively fast adjustment process, meaning that the Romanian economy quickly returns to equilibrium after short-term shocks.

Table 4. ARDL Bounds Test for Cointegration

Test Statistic	Value	Critical Values (n≈30)	I(0)	I(1)
F-statistic	4.610	10%	2.407	3.517
		5%	2.910	4.193
		1%	4.134	5.761

Source: authors' computations in Eviews 12

The results of the Bounds Test confirm the existence of a long-run relationship between economic growth, renewable energy consumption, CO_2 emissions, energy use, gross capital formation and trade openness. The computed F-statistic (4.61) exceeds the upper critical bound, indicating that the null hypothesis of no cointegration can be rejected. This finding suggests that the selected variables move together in the long run and are linked through an equilibrium relationship.

Table 5. Granger Causality Test Results

Null Hypothesis	F-Statistic	Prob.	Conclusion
lnCO2 does not Granger Cause lnGDP	4.21	0.025	Causality
lnEN does not Granger Cause lnGDP	4.08	0.029	Causality
lnCO2 does not Granger Cause lnTR	3.95	0.031	Causality
lnGCF does not Granger Cause lnTR	3.72	0.037	Causality
lnTR does not Granger Cause lnREN	3.58	0.049	Causality
lnTR does not Granger Cause lnGDP	3.12	0.052	Weak causality
lnEN does not Granger Cause lnTR	2.91	0.062	Weak causality
lnREN does not Granger Cause lnGDP	1.98	0.154	No causality
lnGDP does not Granger Cause lnREN	0.41	0.669	No causality

Source: authors' computations in Eviews 12

The results of the Granger causality test reveal several important relationships between the variables. There is evidence of unidirectional causality running from CO_2 emissions and energy use to economic growth, indicating that economic activity in Romania is still influenced by energy consumption and environmental factors.
Additionally, CO_2 emissions and gross capital formation are found to Granger-cause trade openness, suggesting that both environmental pressures and investments play a role in shaping international trade dynamics. A significant causal relationship is also identified from trade openness to renewable energy consumption,

highlighting the role of economic integration in supporting the development of renewable energy.

However, no causal relationship is found between renewable energy consumption and economic growth, indicating that renewable energy has not yet become a significant driver of economic performance in Romania during the analyzed period.

These findings are consistent with previous studies on the energy–growth–environment nexus, while also providing country-specific insights for Romania as a transition economy. In contrast to the findings of Apergis and Payne (2010), who identified a significant relationship between renewable energy consumption and economic growth, the results of this study suggest that renewable energy has not yet reached a sufficient level to significantly influence economic performance. This may be explained by its relatively lower share in the energy mix during the analyzed period.

The empirical results allow us to assess the validity of the research hypotheses.

H1, which states that renewable energy consumption has a positive and statistically significant impact on economic growth in Romania, is rejected. Although the coefficient of renewable energy is positive, it is not statistically significant, indicating that renewable energy has not yet become a key driver of economic growth.

H2, which assumes a significant relationship between CO_2 emissions and economic growth, is supported by the results. Both the long-run relationship and causality analysis confirm that CO_2 emissions are associated with economic activity, reflecting the continued reliance on conventional energy sources.

Overall, the findings suggest that traditional energy sources and investment dynamics remain the dominant factors influencing economic growth in Romania, while renewable energy plays a more limited and emerging role.

4.Conclusions and discussions

This paper examined the relationship between renewable energy consumption, economic growth and environmental indicators in Romania over the period 1990–2022 using a time-series econometric approach. The results provide strong evidence of a long-run relationship between GDP, renewable energy, CO_2 emissions, energy use, capital formation and trade openness.

The findings indicate that renewable energy plays a positive but statistically insignificant and limited role in supporting economic growth, suggesting that its contribution remains modest in the Romanian context. At the same time, the positive relationship between CO_2 emissions and economic growth suggests that Romania is still in a phase where economic expansion relies, to some extent, on carbon-intensive energy sources.

Gross capital formation is identified as a key driver of economic growth, particularly in the short run, highlighting the importance of investment in sustaining economic performance. In contrast, energy use and trade openness do not exhibit statistically significant effects, indicating that their role is less pronounced in explaining economic growth during the analyzed period. The presence of a stable long-run relationship and a significant error correction mechanism highlights the capacity of the Romanian economy to adjust to short-term shocks.

Overall, the study contributes to the literature on the energy–growth–environment nexus by providing country-specific evidence for Romania and by extending previous regional analyses through a detailed time-series perspective.

The results of this study have several important policy implications for Romania's economic and energy strategy. Although renewable energy does not yet have a statistically significant impact on economic growth, its role is expected to increase in the future as investments and technological advancements expand its share in the energy mix. Expanding the capacity of renewable energy sources, such as wind, solar and hydro, may support long-term economic development while reducing dependence on fossil fuels.

At the same time, the positive association between CO_2 emissions and economic growth highlights the need for more effective environmental policies, including improving energy efficiency, promoting cleaner technologies and implementing stricter regulations to reduce carbon intensity. The strong role of investment suggests that policies should prioritize capital formation, particularly in infrastructure and green technologies, to sustain economic growth.

Finally, Romania may benefit from deeper integration into international markets by attracting foreign investment in renewable energy and environmentally sustainable sectors.

This study has several limitations. First, the analysis is based on a single-country time-series, which may limit the generalizability of the results. Second, the relatively small sample size may affect the robustness of the estimations. Future research could extend the analysis using panel data or alternative econometric approaches.

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