



Renewable Energy Use, CO₂ Emissions, Oil Production, and Oil Prices in Relation to Sustainable Economic Growth in Algeria: An ARDL Bounds Testing Approach

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Abstract :

Carbon dioxide (CO₂) emissions are among the key environmental factors linked to economic activity, especially in countries heavily dependent on conventional energy. This study examines the role of renewable energy use, CO₂ emissions, oil production, and oil prices in achieving sustainable economic growth in Algeria, using an ARDL model for the period 2000–2023. The results indicate that per capita CO₂ emissions have a positive and significant impact on per capita GDP in both the short and long term, highlighting the economy's reliance on fossil fuels. Conversely, renewable energy consumption showed no significant long-term effect and had a negative short-term impact, reflecting its weak economic contribution. Crude oil production and prices were found to positively and significantly influence economic growth over both horizons, reaffirming Algeria's dependence on the hydrocarbon sector. The study recommends boosting investment in renewable energy to diversify the energy mix, reduce oil dependency, and promote more sustainable economic growth.

Key Words: Carbon Dioxide Emissions, Renewable Energy, Oil Production, Oil Prices, Sustainable Economic Growth.

JEL Classification: Q43, Q01, C32

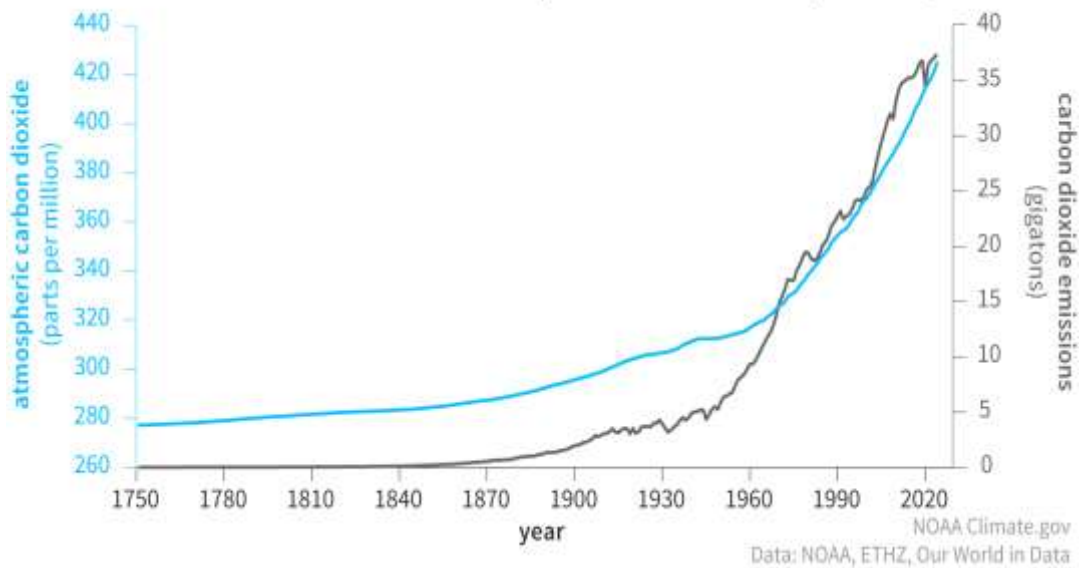
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Introduction :

Carbon dioxide (CO₂) emissions are now the principal driver of anthropogenic climate change, largely because of their role in accelerating global temperature rise. Over the past five decades, global CO₂ emissions have surged by roughly 40 %, primarily owing to the sustained combustion of fossil fuels that still dominate the world's energy mix (İnal, 2022). Figure 1 illustrates the persistent increase in atmospheric CO₂ concentrations, mirroring the close linkage between industrial activity, oil production, and the expanding consumption of fossil fuels since the Industrial Revolution. These emissions have triggered severe environmental consequences rising sea levels, more frequent extreme-weather events, and widespread disruption of ecosystems thereby elevating sustainability to the top of the global policy agenda.



Figure 1 CO₂ Emissions and Atmospheric Concentrations, 1751–2024
Global carbon dioxide emissions and atmospheric carbon dioxide (1751–2024)



Source : Source: Authors, adapted from <https://www.climate.gov/media/12990>

Against this backdrop, securing sustainable economic growth has become a formidable challenge that demands the reconciliation of economic advancement with environmental stewardship (Adanma, 2024, p. 599).. Energy is pivotal to development; however, excessive dependence on fossil fuels intensifies CO₂ emissions and exacerbates environmental degradation at both local and global scales (Mughal, 2022, p. 2). In contrast, the rapid deployment of renewable-energy technologies offers a viable pathway to curb emissions, mitigate environmental harm, and foster sustainable development (Elkhatat, 2024, p. 1). Transitioning to clean energy also diversifies the energy mix, reduces oil import dependence, and cushions economies against the adverse effects of oil-price volatility. Such price swings directly influence investment decisions and consumption patterns across conventional and renewable-energy sectors, thereby shaping the long-term stability and trajectory of economic growth (Murshed, 2021, p. 2).

Algeria, as an oil-producing country with an economy largely dependent on fossil fuels, faces significant challenges related to environmental sustainability and economic diversification. Managing the interplay between renewable energy use, oil production, and fluctuating oil prices is critical for promoting sustainable economic growth in the country.

This study aims to analyze the dynamic relationships between renewable energy use, carbon dioxide emissions, oil production, and oil prices, and how these factors collectively impact sustainable economic growth.

The central research problem of this study can be stated as follows:

What is the nature of the relationship between renewable energy consumption, carbon dioxide (CO₂) emissions, oil production, oil prices, and sustainable economic



growth in Algeria? Furthermore, does a long-run equilibrium relationship exist among these variables?

Hypotheses:

- **H₀:** Renewable energy consumption has a positive effect on economic growth in both the short and long run.
- **H₁:** CO₂ emissions have a positive effect on economic growth in both the short and long run.
- **H₂:** Oil prices have a positive impact on economic growth in both the short and long run.
- **H₃:** Oil production has a positive impact on economic growth in both the short and long run

Objective of the Study: This study aims to analyze the relationship between renewable energy use, carbon dioxide (CO₂) emissions, oil production, and oil prices, on the one hand, and sustainable economic growth, on the other, in Algeria, using the Autoregressive Distributed Lag (ARDL) model. It also seeks to determine the nature of this relationship in both the short and long run, and to assess the impact of each variable on sustainable economic growth. The ultimate objective is to provide policy recommendations that support energy and environmental strategies within the framework of sustainable development.

Importance of the Study: This study fills a critical gap in the Algerian economic literature by empirically linking energy and environmental variables to sustainable growth. Its findings provide policymakers with a robust scientific basis for crafting balanced strategies that reconcile economic expansion with environmental protection, especially amid mounting international pressure to reduce carbon emissions and accelerate the transition to clean energy.

I. Literature Review:

Economic growth is regarded as a fundamental pillar for achieving sustainable development, which relies on balancing economic, environmental, and social dimensions. Energy plays a crucial role in supporting GDP growth, as the use of different energy sources affects both economic performance and the environment through greenhouse gas emissions, notably carbon dioxide. Consequently, transitioning to renewable and clean energy sources has become essential to foster sustainable economic growth while minimizing harmful emissions and preserving environmental quality. Striking a balance between economic growth and emission reduction poses both challenges and opportunities for attaining sustainable and inclusive development. In this context, the literature review will be divided into two sections.

1. Renewable Energy Consumption, CO₂ Emissions, and Economic Growth :

Several studies have explored the complex relationship between renewable energy consumption, CO₂ emissions, and economic growth. Farhani (2013) analyzed 12 MENA countries and found long-run causality where economic growth and emissions drive renewable energy use. Khoshnevis Yazdi (2018) found no evidence



of the EKC in Germany, and noted that high renewable energy costs may hinder growth. Lee (2019) showed that in the EU, renewable energy and exports reduce emissions, while economic growth and industrialization increase them in the short run. Chen (2019) confirmed the EKC for China only when renewable energy is included, with renewable sources and trade reducing emissions. Saidi (2020) found that in 15 major renewable energy-consuming countries, renewable energy supports both growth and emission reduction, with bidirectional causality between growth and renewable energy. Nguyen (2022) revealed that in Vietnam, non-renewable energy boosts income in the long term, while emissions reduce income in the short term. Jeon (2022) confirmed the EKC across 48 U.S. states, showing that renewable energy and energy prices reduce emissions. Kirikkaleli (2022) noted that in Chile, financial development and renewable energy lower emissions, while growth and electricity use increase them. AlNemer (2023) found that in Saudi Arabia, non-renewables drive short-term growth and emissions, while renewables promote long-term growth and environmental quality. Radmehr (2021) confirmed strong spatial relationships in the EU among the variables. Fu (2021) in BRICS countries found feedback between renewables and growth and a one-way link to emissions. Finally, Ahmat (2025) found in Malaysia that non-renewable energy, overall energy use, and economic growth all contribute to higher emissions in both the short and long term.

2. Oil Production, Oil Prices, and Economic Growth :

A growing body of research has examined the impact of oil production and price dynamics on economic growth. Bildirici (2013) showed a bidirectional long- and short-run relationship between oil production and economic growth in European oil-exporting countries. Ogboru (2017) found that in Nigeria, oil prices positively influence GDP, recommending diversification and refinery upgrades. Aimer (2019) revealed a long-run positive effect of oil price shocks on Libya's GDP, with causality running both ways. Krishkumar (2022) observed that in Malaysia, both rising and falling oil prices positively impact growth, reflecting asymmetric effects. Mahmood (2022) showed that in GCC countries, economic growth and urbanization raise emissions, while oil price effects vary by country. Elneel (2022) reported that in Saudi Arabia, oil shocks negatively affect long-term growth, but non-oil exports help support it, aligning with Vision 2030. Abdelsalam (2023) found that in MENA countries, oil price volatility affects growth asymmetrically, depending on country-specific factors, while institutional quality reduces the negative impacts. Gafsi (2025) found that in Saudi Arabia, oil prices and renewable energy promote sustainable growth, while CO₂ emissions hinder it and oil production shows no significant effect. Deyshappriya (2023) concluded that in OECD countries, rising oil prices have an overall negative impact on growth, mainly through adverse effects on investment, exchange rates, and government spending. Miamo (2021) demonstrated a positive impact of oil prices on GDP in Cameroon, with causality running from GDP to oil prices.

Despite numerous studies examining the relationship between renewable energy consumption, carbon dioxide emissions, oil production, oil prices, and economic



growth, most have focused on specific countries or economic blocs, such as Saudi Arabia, Vietnam, the European Union, and the BRICS countries, or have relied on panel data covering a number of countries without focusing on a specific case. Many of these studies have also analyzed only two or three variables, without comprehensively integrating all these factors into a single model that measures their combined impact on sustainable economic growth. Given the unique nature of the Algerian economy, its heavy reliance on oil as a primary source of revenue, and the growing trend toward diversifying energy sources and transitioning to a more sustainable economy, the need for a study that integrates renewable energy consumption, carbon emissions, oil production, and oil prices to explain the path of sustainable economic growth emerges. Hence, the importance of this study lies in bridging this gap, not only in terms of its focus on the Algerian case, but also in terms of the comprehensiveness of the variables that will address the dynamic relationship between all the aforementioned factors combined—something that previous studies in this context have not addressed.

II. Data and Methodology:

Taking into account the findings of the literature review presented in the previous section, an Autoregressive Distributed Lag (ARDL) model is employed. This model enables the identification of both short-run and long-run complementary relationships between the dependent variable and the independent variables within a single-equation framework. Specifically, the ARDL model is used to examine the potential complementary relationship between GDP per capita (GDPPER) and the following explanatory variables: per capita CO₂ emissions from fossil fuels (FCO2PER), renewable energy consumption (REN), oil production (OILP), and oil prices (OILPRICE) in the Republic of Algeria over the period 1990–2023.

Accordingly, the following econometric model is specified to achieve the objectives of this research:

$$GDPPER_t = f(FCO2PER_t, REN_t, OILP_t, OILPRICE_t,)$$

1. Data Sources:

The definitions and measurement units of all variables are presented in Table 1 below.

Table 1: Model variables and sources

Variable	Symbol	Source
GDPPER	GDP per capita	World Bank
FCO2 PER	Fossil CO2 emissions per capita (tons)	World Bank
REC	Renewable energy consumption (% of total final energy consumption)	World Bank
OILP	Cude oil production (Mln t)	World Bank
OILPRICE	Crude oil price	www.macrotrends.net

Source: Prepared by the researchers.



2. Methodology: The ARDL approach to cointegration:

The current study employs the Autoregressive Distributed Lag (ARDL) model to estimate the study's framework. This methodology, developed by Pesaran et al. (2001) (Natsiopoulou, 2024, p. 4), is used to examine whether there is a long-run equilibrium relationship (cointegration) among the study variables (Dube, 2018, p. 6).

This approach differs from the Engle & Granger and Johansen methods in that it yields better results when dealing with short time series (Katrakilidis, 2012, p. 6). Moreover, it does not require the time series to be integrated of the same order, as it can be applied when the variables are integrated of order I(0) or I(1) (Nkoro, 2016, p. 78). provided that none of the variables are integrated of order two (I(2)) (Obwori Alwago, 2025, p. 7). Additionally, the ARDL model allows for the simultaneous estimation of both short- and long-run relationships among the variables.

The description of our ARDL model can be presented as follows:

$$\begin{aligned}
 GDPPER_t = \varphi_0 + \sum_{i=1}^k \varphi_1 \Delta GDPPER_{t-i} + \sum_{i=0}^k \varphi_2 \Delta CO2PER_{t-i} + \sum_{i=0}^k \varphi_3 \Delta REN_{t-i} \\
 + \sum_{i=0}^k \varphi_4 \Delta OILP_{t-i} + \sum_{i=0}^k \varphi_5 \Delta OILPRICE_{t-i} + \lambda_1 GDPPER_{t-1} \\
 + \lambda_2 CO2PER_{t-2} + \lambda_3 OILP_{t-1} + \lambda_4 REN_{t-1} + \lambda_5 OILPRICE_{t-1} + \varepsilon_t
 \end{aligned}$$

Where Δ is the first difference operator, $GDPPER_t$ is the dependent variable, $CO2PER$, REN and $OILP$, $OILPRICE$ are the explanatory variables, ε_t is the white noise error term

where φ_1 to φ_5 are the long run relationships, whereas λ_1 to λ_5 are the short run dynamics of the model. The null hypothesis (H_0) in this equation is $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = 0$, which implies the non-existence of a long run relationship, whereas its rejection implies its existence (Ferraz, 2025, p. 150). Accordingly: 1) if the F-test value is inferior to the lower bound critical value, we cannot reject H_0 of non-cointegration; 2) if we utilize F statistics. If the calculated F statistic is greater than the upper critical value at the 5% significance level, we reject the null hypothesis of no long-run cointegration. Conversely, if the Wald F statistic falls below the lower bound of the tabulated F statistic at the 5% significance level, we fail to reject the null hypothesis of no long-run cointegration. (Lorato, 2025, p. 10).

An Error Correction Model (ECM) version of the ARDL can also be estimated, which can be presented as follows:

$$\begin{aligned}
 GDPPER_t = \varphi_0 + \sum_{i=1}^k \varphi_1 \Delta GDPPER_{t-i} + \sum_{i=0}^k \varphi_2 \Delta CO2PER_{t-i} + \\
 \sum_{i=0}^k \varphi_3 \Delta REN_{t-i} + \sum_{i=0}^k \varphi_4 \Delta OILP_{t-i} + \sum_{i=0}^k \varphi_5 \Delta OILPRICE_{t-i} + \alpha ECT_{t-1} + \varepsilon_t
 \end{aligned}$$

α Serves as a stand-in for the adjustment rate in equation (6). It shows how quickly changes in the short term in the current year rectify long-term aberrations from the prior year. To confirm statistical significance, the error correction specification



(ECT) is expected to display a negative sign and a p-value less than 5%. (Srithilat, 2025, p. 34)

- Stationarity Tests: To make sure the time series data is stationary, do tests such as the Augmented Dickey-Fuller (ADF) test.
- Cointegration Tests: To look for long-term equilibrium relationships between variables, use tests such as the Johansen Cointegration test.

III. Econometric Results, and diagnostic :

1. Description Variables:

full details on each variable presented in Table 1, which provides the number of observations, maximum and minimum values, standard deviations (STD), skewness, kurtosis and mean value.

Table 2 : Description of Variables

	GDPPER	FCO2PER	OILP	OILPRICE	REN
Mean	4074.832	3.405	781.823	50.398	0.335
Median	4307.858	3.35	762.5	45.975	0.35
Maximum	4768.731	4.2	1006	99.67	0.7
Minimum	3201.569	2.8	649	14.42	0.1
Mean	4074.832	3.405	781.823	50.398	0.3352
Std. Dev.	544.337	0.444	113.063	28.659	0.175
Skewness	-0.3088	0.305	0.784	0.380	0.231
Kurtosis	1.483	1.728	2.466	1.745	2.232
Jarque-Bera	3.797	2.818	3.889	3.049	1.138
Probability	0.149	0.244	0.143	0.217	0.565
Sum	138544.307	115.8	26582	1713.55	11.399
Sum Sq. Dev.	9778009.077	6.518	421852.94	27105.201	1.017
Observations	34	34	34	34	34

Source: Prepared by the researchers.

We note from this table that the number of observations is 34, with the average per capita gross domestic product (GDP per) being approximately \$4,074, the average CO₂ emissions (FCO2 per) at 3.4 tons, average oil production (OILP) at 781 thousand barrels, oil price (OILPRICE) at \$50.4, and average renewable energy consumption (REN) at 33.5%. The standard deviation, skewness, and kurtosis values indicate moderate variability in the variables, with no significant departures from normality according to the Jarque-Bera test.

2. Time Series Stationarity Test:

The stationarity of the time series for the study variables namely, the unemployment rate, public spending rate, economic growth rate, oil price, population growth rate, and domestic investment rate was tested using the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) unit root test. The results presented in Tables 2 and 3, based on the application of both ADF and PP tests, indicate that the findings are consistent across the two methods and that the time series of the economic variables



are non-stationary at their levels. All estimated test statistics are lower in absolute value than the corresponding critical values, implying statistical insignificance. Accordingly, the null hypothesis of non-stationarity at level was accepted.

To achieve stationarity, the first differences of all variables were taken. Using the same two tests, it was found that all variables became stationary in their first difference at significance levels of 1%, 1%, and 12%, respectively. From this, it can be concluded that all variables are integrated of order one, i.e., I (1). Therefore, the Autoregressive Distributed Lag (ARDL) model can be employed, as the necessary condition for its use is satisfied.

Table 3 : ADF unit root tests

Variables	Intercept			Trend and intercept			None		
	Level	First diff	Order of integration	Level	First diff	Order of integration	Level	First diff	Order of integration
GDPPER	- 0.310 (0.912)	-4.003 (0.004***)	I (1)	-1.639 (0.754)	-3.934 (0.022***)	I (1)	1.772 (0.979)	-3.620 (0.000***)	I (1)
FCO2PER	-1.397 (0.571)	-8.292 (0.000***)	I (1)	-2.672 (0.253)	-8.161 (0.000***)	I (1)	0.991 (0.911)	-8.193 (0.000***)	I (1)
REN	-1.907 (0.324)	-6.399 (0.000***)	I (1)	-1.841 (0.661)	-6.417 (0.000***)	I (1)	-0.247 (0.589)	-6.437 (0.000***)	I (1)
OILP	-1.138 (0.688)	-4.165 (0.002***)	I (1)	-0.845 (0.950)	-4.318 (0.009***)	I (1)	-0.049 (0.659)	-4.235 (0.000***)	I (1)
OILPRICE	-1.561 (0.490)	-5.847 (0.000***)	I (1)	-2.319 (0.412)	-5.731 (0.000***)	I (1)	-0.241 (0.591)	-5.861 (0.000***)	I (1)

Source: Prepared by the researchers.

Table 4: PP unit root tests

Variables	Intercept			Trend and intercept			None		
	Level	First diff	Order of integration	Level	First diff	Order of integration	Level	First diff	Order of integration
GDPPER	-0.541 (0.870)	-3.969 (0.004***)	I (1)	-2.112 (0.520)	-3.934 (0.022***)	I (1)	1.283 (0.946)	-3.599 (0.000***)	I (1)
CO2PER	-1.109 (0.700)	-8.611 (0.000***)	I (1)	-2.642 (0.265)	-8.479 (0.000***)	I (1)	0.507 (0.820)	-8.211 (0.000***)	I (1)
REN	-1.907 (0.324)	-6.433 (0.000***)	I (1)	-1.841 (0.661)	-6.458 (0.000***)	I (1)	-0.007 (0.673)	-6.477 (0.000***)	I (1)
OILP	-1.525 (0.508)	-4.335 (0.001***)	I (1)	-1.179 (0.898)	-4.388 (0.007***)	I (1)	-0.133 (0.630)	-4.398 (0.000***)	I (1)
OILPRICE	-1.461 (0.540)	-5.962 (0.000***)	I (1)	-2.365 (0.389)	-5.822 (0.000***)	I (1)	-0.014 (0.670)	-5.945 (0.000***)	I (1)

1) *, **, *** denote statistically significant at the 10%, 5% and 1% levels, respectively P-value is inside brackets Source: Authors. GDPPC: Gross domestic product per capita, F CO2EPC: Fossil CO2 emissions per capita, REC: Renewable energy consumption, COProd: Cude oil production, COPrice: Crude oil price

Source: Prepared by the researchers.

**Table 5: Selection order criteria:**

Lag	Logl	LR	FPE	AIC	SC	HQ
0	-552.4364	NA	9.30e+08	34.83978	35.06880	34.91569
1	-432.4497	194.9784*	2510954.*	28.90311	30.27724*	29.35859*
2	-406.5197	34.03313	2680432.	28.84499*	31.36422	29.68004

Source: Prepared by the researchers.

Table 6: Noncausality tests in the sense of Granger for the vector autoregressive (1) (1990-2023)

Dependent Variabl	Excluded Variables	P	Direction of causality
GDPPER	FCO2PER, REN, OILP, OILPRICE	0.8549	does not granger cause
FCO2PER	GDPPER, REN, OILP, OILPRICE	0.1196	does not granger cause
REC	GDPPER, FCO2PER, OILP, OILPRICE	0.2917	does not granger cause
OILP	GDPPER, FCO2PER, REN, OILPRICE	0.1155	REN, FCO2PER, OILPRICE do not Granger cause OILP, but GDPPER Granger causes OILP (p=0.020)
OILPRICE	GDPPER, FCO2PER, REN, OILP	0.0981	REN, FCO2PER, OILPRICE do not Granger cause OILP, but GDPPER Granger causes OILP (p=0.020)

Source: Prepared by the researchers.

We note from the results of the Granger Causality test that there are no significant causal relationships between most of the economic and environmental variables studied during the period 1990–2023. The results showed that per capita GDP (GDPPER) is not affected by any other variables such as per capita carbon dioxide emissions (FCO2PER), renewable energy (REN), oil production (OILP), or oil price (OILPRICE), indicating that these variables have no causal effect on individual economic growth. Conversely, we observed a significant causal effect of per capita GDP on oil production (OILP) with a significance level of 0.02, indicating that changes in economic activity clearly affect oil production. Furthermore, there is a marginal relationship (close to statistical significance) between oil production and oil price (OILPRICE) with a value of 0.05, indicating that oil production may have a limited impact on oil prices, although the relationship is not entirely strong. As for the causal relationships between other variables such as carbon dioxide emissions, renewable energy, and oil prices, insufficient statistical evidence was found to support the existence of causality between them.

3. Bounds of cointegration test :

To examine whether a long-term equilibrium relationship exists among the variables, the Bound Test will be performed by calculating the F-statistic and comparing it with



the critical values provided by Pearson et al. (2001). The results of the Bound Test are presented in Table 7

Table 7: Bounds of cointegration test

F-Bounds			Null Hypothesis : No levels relationship		Decision
Test Statistic	Value	Signif	I (0)	I (1)	
F- Statistic	23.431358	10%	2.525	3.56	Cointegration
K		5%	3.058	4.223	
		1%	4.28	5.84	

Source: Prepared by the researchers.

The results presented in the table indicate that the calculated test statistic value (23.431358) exceeds the critical value from the Fisher distribution (F) at the (1%, 5%, 10%) significance level, based on the Narayan and Pesaran et al. methodology. This provides robust evidence to reject the null hypothesis and accept the alternative hypothesis, thereby confirming the existence of a cointegration relationship among the variables under study.

4. Estimating the long-run and short-run relationships using the ARDL model:

4.1. The Estimation of Long-Term Transactions According to ARDL Methodology:

After confirming the existence of a cointegration relationship at various significance levels (10%, 5%, 1%), we measured the long-run relationship within the ARDL model. The long-run relationship was estimated by testing the long-run significance of the coefficients of the explanatory variables. The results are shown in Table 3.

The results of estimating the long-run relationship using the ARDL model showed the following:

- Renewable Energy Consumption: The coefficient was not statistically significant. This indicates that renewable energy is not yet an effective or influential source of long-term per capita economic growth, meaning it does not make a significant contribution to per capita GDP. This may be attributed to weak investment or limited reliance on renewable energy in the national economy.
- Carbon Dioxide (CO₂) Emissions: This variable was statistically significant, suggesting a strong relationship between economic growth and increased carbon emissions in Algeria. This reflects the reliance of economic activity on polluting energy sources, such as fossil fuel-based industries.
- Oil Price and Oil Production: Both variables were statistically significant. This result indicates that the volume of oil production clearly contributes to per capita GDP, highlighting the vital role of the hydrocarbon sector in the national economy.

Furthermore, both oil price and oil production have a significant positive effect on per capita GDP in Algeria. This finding is consistent with economic theory and confirms the rentier nature of the Algerian economy, as well as its close dependence



on hydrocarbon revenues, which continue to play a pivotal role in the country's economic performance.

Table 8: Estimated Long-Run Coefficients (ARDL Model)

Variables	Coefficients	Std. Error	t-Statistic	Probability
GDPER(-1)*	-0.660085	0.151049	-4.370001	0.0003
FCO2PER(-1)*	913.2199	110.1098	8.293721	0.0001
REN(-1)	767.0211	427.1899	1.624391	0.1483
OIL(-1)	1.764712	0.364608	4.480033	0.0019
OILPRICE(-1)	4.409117	1.275945	3.455570	0.0106
C	-2251.555	488.1705	-4.612230	0.0024

*p-values are incompatible with t-bounds distribution

Source: Prepared by the researchers.

4.2. Error Correction Model According to ARDL Methodology:

We note from Table 2 that the error correction coefficient was negative (-0.66) and statistically significant at the 0.000 level, confirming the existence of a cointegration relationship among the variables under study. The estimated error correction coefficient value of -0.66 means that approximately 66% of the deviation of GDP per capita from its long-run equilibrium value is corrected within the current year. Accordingly, it takes approximately one and a half years to reach its long-run equilibrium value.

The model also indicates that all variables are statistically significant except for renewable energy consumption, which has a negative impact on GDP per capita in the short run. The effects of other variables, such as oil prices, production, and carbon dioxide emissions, vary between positive and negative depending on the degree of lag. In addition to the high value of the adjusted coefficient of determination (Adjusted $R^2 = 0.95$), which indicates that the estimated model explains 92% of the variations in the dependent variable.

Table 9: Short-Term Estimations and Error Correction

Variables	Coefficients	Std. Error	t-Statistic	Probability
COINTEQ*	-0.660085	0.042519	-15.52444	0.0000
D(GDPPER(-1))	-0.282620	0.102566	-2.755487	0.0174
D(FCO2PER)	457.4364	27.51164	16.62701	0.0000
D(FCO2PER(-1))	-172.9958	28.47214	-6.075969	0.0001
D(REN)	25.30358	41.65141	0.607508	0.5548
DREN(-1)	-886.7903	81.55733	-10.87321	0.0000
D(OILP)	1.049706	0.181938	5.769572	0.0001
D(OILP(-1))	3.177387	0.381850	8.321040	0.0000
D(OILPRICE)	6.050644	0.568888	10.63591	0.0000
D(OILPRICE(-1))	-9.013466	0.621254	-14.50851	0.0000
R-squared	0.98137	Mean dependent var		45.24953
Adjusted R-squared	0.954656	Durbin -Watson stat		2.269377

*p-values are incompatible with t-bounds distribution

Source: Prepared by the researchers.



5. Testing the Condition of Independence of Independent Variables (Absence of Multicollinearity):

To verify the absence of multicollinearity among the independent variables in the estimated model, the Variance Inflation Factor (VIF) was used. The higher the VIF value, the greater the severity of linear correlation between variables. Typically, VIF values exceeding 10 are considered indicative of a multicollinearity problem among the independent variables. The VIF was calculated for the model variables, and the results are presented in Table 5.

Table 10: Results of the Variance Inflation Factor (VIF) Test for the Study Variables

Variables	Variance Inflation Factor (VIF)
(tons) Fossil CO2 emissions per capita	1.96
Cude oil production	1.78
Renewable energy consumption	2.72
Crude oil price	1.40

Source: Prepared by the researchers.

We note from the table results that the VIF value for each independent variable in the model is less than 10, indicating that there is no linear relationship between the independent variables.

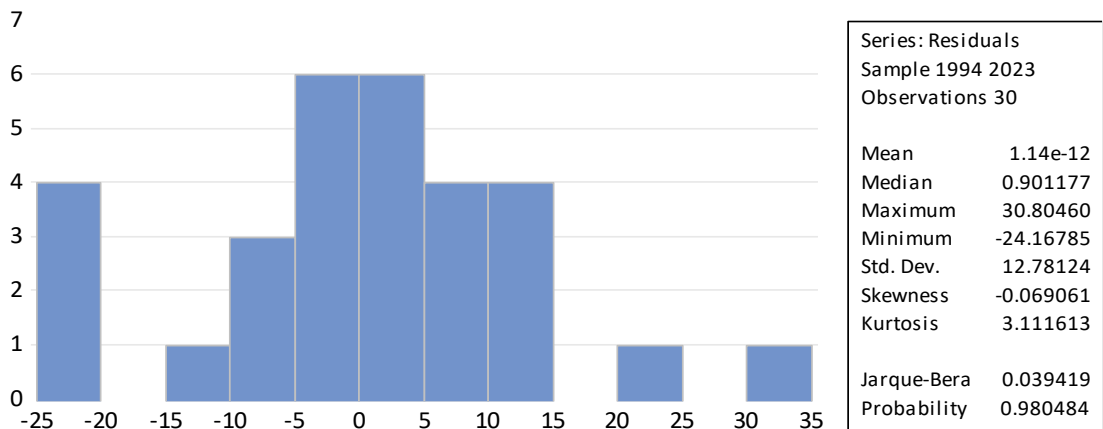
6. Diagnostic Tests:

Following the confirmation of the model's economic and statistical validity, it is essential to assess its adequacy by examining its consistency and ensuring it is free from common issues. This evaluation is conducted through a series of diagnostic tests, as outlined below:

This test is designed to verify the validity of the estimated model and to confirm that it is not affected by standard problems typically associated with time series analysis. The diagnostic tests are applied to the model residuals, and the corresponding results are summarized in the tables below.

6.1. Jarque-Bera test:

Figure 2 shows the results of the Jarque-Bera test. the p-value of the test is 0.980484 which is greater than 5%. Therefore, the model residuals are normally distributed, and there is no issue related to non-normality:

**Figure 2: Results of the Jarque-Bera Test**

Source: Prepared by the researchers.

6.2. Testing the Hypothesis of No Autocorrelation Among the Model Residuals:

The following table presents the results of testing the null hypothesis that the residuals are not independent, using the Breusch–Godfrey Serial Correlation LM Test. The results indicate that there is no statistical evidence to reject the null hypothesis, implying that there is no autocorrelation among the residuals, as the p-value is 0.4548, which exceeds the 5% significance level.

Table11: Breusch–Godfrey Test for Examining the Hypothesis of No Autocorrelation in the Model Residuals

Breusch-Godfrey Serial Correlation LM Test:

Null hypothesis: No serial correlation at up to 2 lags

F-statistic	0.926185	Prob. F(2,5)	0.4548
Obs*R-squared	8.109765	Prob. Chi-Square(2)	0.0173

Source: Prepared by the researchers.

6.3. Homogeneity (Stability) of the Variance of the Model Residuals (Errors):

there are several tests used to assess whether the variance of the residuals is homogeneous, including the ARCH test. To verify the homogeneity of the error terms, the results are shown in Table 1. The test statistic is 0.2569 with a p-value greater than 5%, which supports accepting the null hypothesis that the variance of the error terms is homogeneous.

Table 12: The condition of homoscedasticity of the model's error terms

Heteroskedasticity Test: ARCH

F-statistic	1.341768	Prob. F(1,27)	0.2569
Obs*R-squared	1.372930	Prob. Chi-Square(1)	0.2413

Source: Prepared by the researchers.

The Breusch-Pagan-Godfrey test was also employed, and the results are presented in the following table. These results indicate that there is no statistical evidence to reject



the null hypothesis, implying that there is no issue of heteroscedasticity. The test statistic reached 0.2451, which corresponds to a p-value greater than the 5% significance level.

Table 13 : The condition of homoscedasticity of the model's error terms

Heteroskedasticity Test: Breusch-Pagan-Godfrey

Null hypothesis: Homoskedasticity

F-statistic	1.687277	Prob. F(22,7)	0.2451
Obs*R-squared	25.24026	Prob. Chi-Square(22)	0.2857
Scaled explained SS	1.450881	Prob. Chi-Square(22)	1.0000

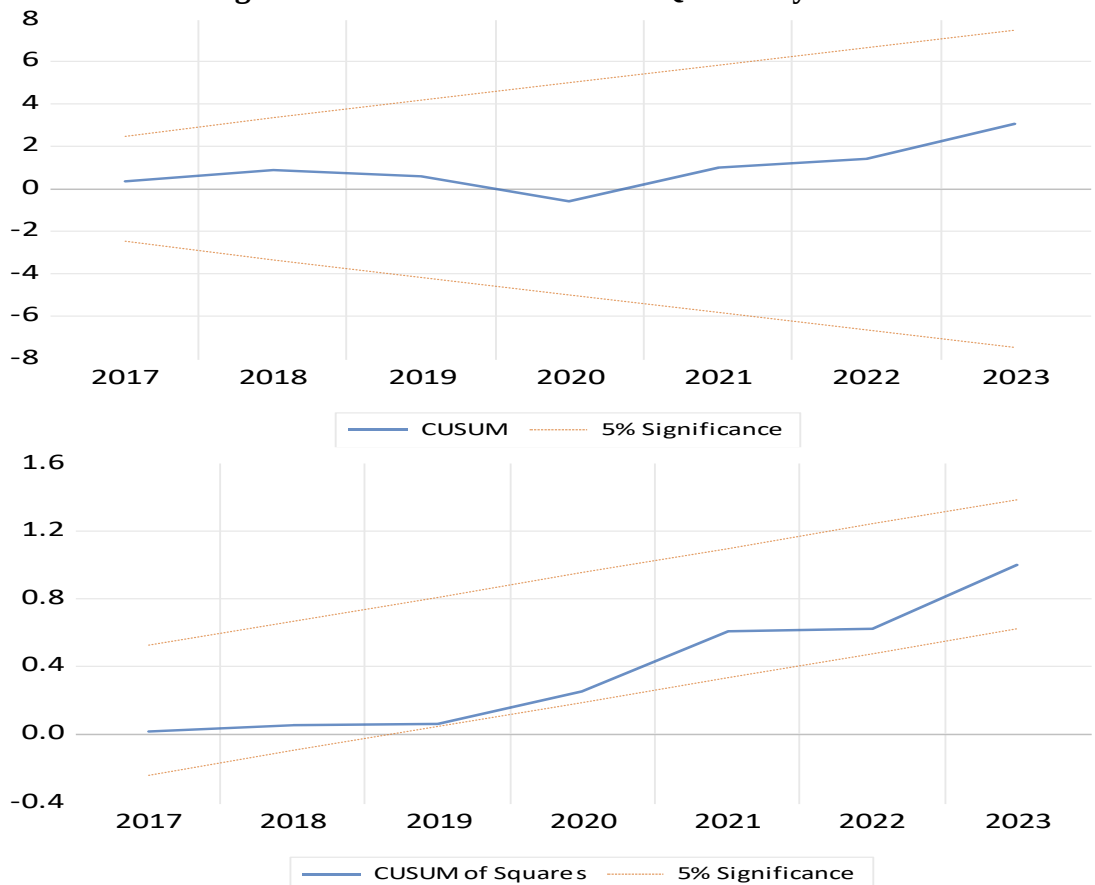
Source: Prepared by the researchers.

6.4. Structural Stability Test of the Model :

Two tests were used to assess the stability of the mode: the cumulative sum (CUSUM) test and the cumulative sum of squares of recursive residuals (CUSUMSQ) test. To confirm the model's stability, the graphs of both tests must remain within the critical bounds at the 1% significance level. If this condition is met, the null hypothesis—that all estimated parameters are stable can be accepted.

Figure 2 shows that the model is both stable and stationary

Figure 3: CUSUM and CUSUMSQ Stability Tests



Source: Prepared by the researchers.



IV. Analysis and Interpretation of the Results:

-The insignificance of the renewable energy consumption coefficient indicates that this sector does not effectively contribute to per capita economic growth. This can be attributed to weak investments in renewable energy or to limited reliance on it within the national economy, thereby diminishing its impact on GDP.

-The relationship between carbon dioxide emissions and per capita economic growth was found to be positive and statistically significant. This reflects the continued heavy dependence on traditional energy sources, particularly fossil fuel-based industries, confirming that current economic growth is occurring at the expense of the environment.

-Both oil prices and production exhibited a clear and statistically significant contribution to per capita GDP, underscoring the pivotal role of the hydrocarbon sector in supporting economic performance. This also confirms the rentier nature of the economy, which is highly vulnerable to fluctuations in the global oil market.

-The effect of renewable energy consumption was also negative, suggesting that the transition to this energy type is still in its early stages and has not yet reached the point of generating tangible added value for the national economy.

-Other variables, including oil prices, production volume, and carbon emissions, showed varying impacts on GDP per capita. These effects differ across time periods, indicating that economic growth is significantly influenced by fluctuations in these factors related to natural resources and environmental pressures.

Conclusion:

The study aims to assess the long- and short-term impact of important factors, such as fossil carbon dioxide emissions, renewable energy consumption, and crude oil production and price, on sustainable economic growth in Algeria. The variables were measured for the period 2000-2021. Using the ARDL model, the following were identified:

The results showed a long-term complementary relationship between the variables under study, confirming a balanced correlation between them in the long run. In this context, carbon dioxide emissions were found to have a significant positive impact on economic growth, reflecting the Algerian economy's reliance on polluting traditional energy sources such as the oil and gas sector.

On the other hand, the results showed a weak impact of renewable energy consumption on economic growth, indicating that the sector's contribution remains limited due to the lack of investment and support directed at it. Therefore, developing the renewable energy sector and providing an investment-friendly environment are essential to boosting economic growth and achieving environmental sustainability. It also showed that oil prices and production have a strong, positive impact on per capita GDP, reflecting the vital role of the hydrocarbon sector in supporting the national economy and the country's heavy reliance on it as a primary source of revenue.

Based on these findings, it becomes imperative to rethink Algeria's economic development strategies by reducing dependence on oil and adopting sustainable



energy policies that integrate renewable energy sources more effectively. This will contribute to achieving long-term, environmentally sustainable economic growth, reduce environmental damage associated with pollution, and ensure a more stable and prosperous future for the national economy.

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