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Article

CO_2 Emissions in Algeria: An Econometric Investigation of Financial Inclusion, Economic Growth, and Natural Resource Rents

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Abstract

This study investigates the dynamic relationships between financial inclusion, economic growth, natural resource rents, and CO_2 emissions in Algeria over the period 1990–2023. Employing the ARDL bounds testing approach to cointegration and error correction modeling, the analysis reveals significant long-run and short-run linkages among the variables. The findings indicate that economic growth exhibits an Environmental Kuznets Curve (EKC)-type relationship with emissions, reflecting a transitional phase where environmental degradation increases with income. Financial inclusion, while enhancing economic participation, contributes positively to CO_2 emissions, suggesting a lack of green financial governance. Furthermore, natural resource rents display a robust and positive correlation with carbon emissions, challenging the assumption of

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resource-led sustainability and highlighting deficiencies in resource revenue management. These results underscore the need for policy integration between financial and environmental systems. The study recommends the implementation of green financial policies, such as environmentally conditional credit frameworks, investment in renewable energy infrastructure, and the establishment of a sovereign wealth fund dedicated to sustainable development. By addressing these dimensions, Algeria can reconcile economic advancement with its climate commitments and move towards a low-carbon, inclusive growth model.

Keywords: Financial inclusion, CO_2 emissions, Natural resource rents, Environmental Kuznets Curve, ARDL model, Algeria.

1. Introduction:

Algeria stands at a critical juncture in its development trajectory, facing the dual challenge of fostering inclusive economic growth while addressing urgent climate commitments. As Africa's third-largest CO_2 emitter (World Bank, 2022) and a hydrocarbon-dependent economy where oil and gas constitute 90% of export earnings (IMF, 2024), the country exemplifies the tension between resource-driven development and environmental sustainability. This study investigates how Algeria's financial inclusion policies, economic expansion, and natural resource management intersect to shape its carbon emissions.

The Algerian paradox presents a compelling research context: while financial inclusion rates surged from 26% to 45% of adults between 2011-2021, coinciding with GDP growth averaging 3.1% annually (World Bank, 2025), CO_2 emissions per capita remain stubbornly high at 3.6 metric tons - 53% above the African average(Our World in Data, 2025). This juxtaposition raises critical questions about the sustainability of Algeria's development model, particularly as it seeks to diversify its economy under the constraints of declining oil production and increasing climate vulnerability, with temperatures rising 1.5°C since pre-industrial levels.

Existing literature reveals three critical gaps this study addresses. First, while the financial inclusion-emissions nexus has been examined globally (Sadorsky, 2010) few studies focus on African hydrocarbon economies where financial systems prioritize fossil fuel financing. Second, Algeria's unique position as a rentier state implementing financial inclusion policies remains underexplored, despite evidence that 78% of SME loans flow to carbon-intensive sectors (energy institute, 2025). Third, the interaction between resource rents and financial development in shaping emissions requires empirical validation, particularly given Algeria's $7 billion annual fossil fuel subsidies (IMF, 2024).

This paper seeks to examine the impact of financial inclusion, economic growth and natural resource rents on Co2 emissions in Algeria. By analyzing data For Algeria, this research aims to shed light on the varying degrees of influence that Financial inclusion, economic growth and natural resource rents has on Co2. Using advanced econometric techniques, such as the (ARDL), the study will explore the nuanced relationships between financial inclusion, economic growth and natural resource rents and Co2 emissions.

2. Literature Review:

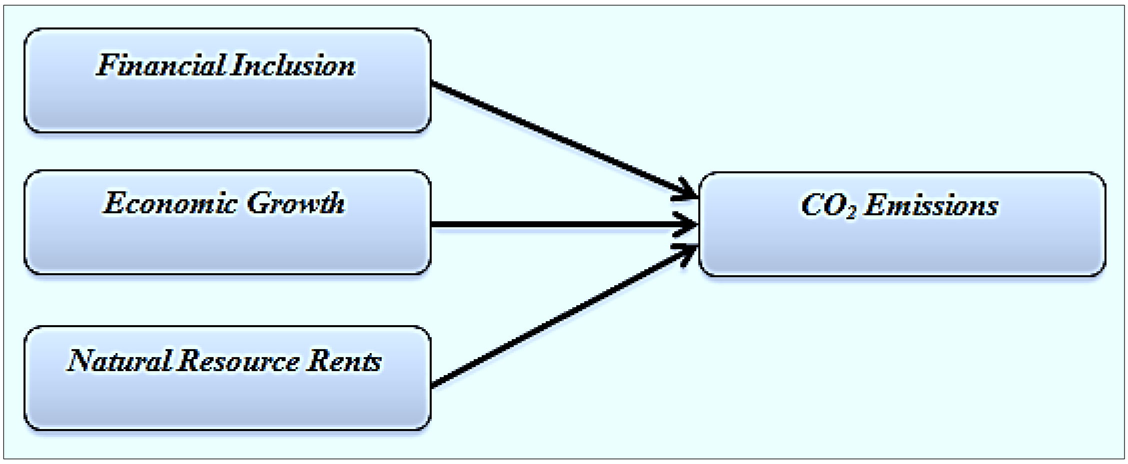

Figure 1. Research framework of the study.

2.1 Financial inclusion- Co2 emissions nexus

The nexus between financial inclusion and environmental degradation, particularly CO_2 emissions, has attracted increasing scholarly attention as countries strive to achieve inclusive growth without compromising environmental sustainability. A growing body of literature has investigated this relationship, yet the results remain mixed, influenced by the heterogeneity in national development levels, institutional quality, and the chosen proxies for financial inclusion. Numerous studies confirm a positive link between financial inclusion and environmental degradation. For instance, (Ullah, Ali, Ali Shah, & Ehsan , 2022) conducted an empirical analysis on OECD countries and found that financial inclusion intensifies CO_2 emissions, particularly in less-globalized economies. Similar conclusions are drawn by (Ahmad, et al., 2022) for the BRICS countries, where access to financial services stimulates economic activity and emissions, though moderated by green openness and technological innovation. In contrast, evidence from China illustrates the complexity of this relationship. (Dong, Dou, Jiang, & Zhao , 2022)reports that financial inclusion impedes environmental sustainability and delays energy-related technological innovation. However, (Liu, Hong, & Sohail, 2021) provides a more differentiated perspective, suggesting that certain financial inclusion indicators can improve environmental quality, especially when mediated by educational attainment and financial literacy. Region-specific dynamics also emerge in South Asia. (Amin, Song, & Khan, 2022)reveals that financial inclusion and modernization jointly accelerate emissions, though these effects are partly mitigated by trade openness and regional integration. On a broader global scale, (Shah, Yasmeen, & Padda, 2019)finds a universal positive association between financial development and CO_2 emissions across 101 countries, but highlights that institutional quality plays a crucial moderating role. Mixed evidence characterizes the Organization of Islamic Cooperation (OIC) countries.(Chaudhry, Yusop, & Habibullah , 2021)demonstrates that financial inclusion can simultaneously increase certain emissions (CO_2, CH_4) and decrease others (N_2O), as well as reduce ecological footprints, suggesting the presence of nonlinearities and conditional effects. Likewise, the study validates the Environmental Kuznets Curve (EKC) under various income regimes. In the Algerian context, (necib & nid, 2024)confirms a long-run positive relationship between financial sector development and CO_2 emissions, utilizing a composite index framework. Mediating variables such as foreign direct investment and trade openness were found to amplify the effect, reflecting the broader challenges of aligning financial inclusion with environmental policy. Finally, in the context of OBOR (One Belt One Road) countries, (Tsimisaraka , et al., 2023)highlights that both financial inclusion and ICT infrastructure exacerbate emissions, while renewable energy and globalization play significant mitigating roles—particularly in the long run.

Hypothesis H1.Financial inclusion significantly influences CO_2 emissions in Algeria.

2.2. Economic growth- Co2 emissions nexus

The relationship between economic growth and environmental degradation has been a longstanding focus in environmental economics. Central to this discourse is the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between income and pollution—suggesting that while early stages of economic growth may worsen environmental quality, further growth eventually leads to ecological improvement as economies transition to cleaner technologies and stricter regulations.

However, empirical findings remain inconclusive and context-dependent. (González-Álvarez & Montañés), through a multi-country analysis, identify structural breaks—especially the 2008 global financial crisis—as influential in the emissions-growth nexus. Their study shows that developed economies have managed to decouple CO_2 emissions from growth, while emerging economies still rely heavily on carbon-intensive processes. Contrary to the EKC hypothesis, (Mikayilov, Galeotti, & Hasanov, 2018)observe a persistent positive relationship between GDP and CO_2 emissions in Azerbaijan, even after employing advanced techniques such as ARDL, FMOLS, and CCR. Their findings suggest that economic expansion continues to elevate emissions, emphasizing the role of energy structure and policy deficiencies. In developing countries, the dynamics are more nuanced.(Aye & Edoja, 2017), using a dynamic panel threshold model, report a U-shaped relationship between growth and emissions across 31 developing nations. Their results suggest that low-growth regimes may benefit from emission reductions, but at higher growth thresholds, industrialization and infrastructure expansion aggravate environmental degradation. African economies further illustrate regional disparities. (Onofrei, Vatamanu, & Cigu, 2022), utilizing a two-step system GMM approach for 52 African countries, confirms a strong positive relationship between growth, energy consumption, and CO_2 emissions, albeit with significant intra-regional variation. Similarly, (Espoir, Sunge , & Bannor , 2023)provides panel evidence for 47 African countries, supporting the EKC hypothesis. Notably, renewable energy and governance quality emerge as critical moderating variables, suggesting that the transition to green growth hinges on institutional capacity. In Asia, (Karedla, Mishra, & Patel, 2021) focuses on India, where economic growth and manufacturing lead to increased emissions, despite trade openness exerting a reducing effect. These findings reflect the carbon intensity of industrial expansion in fast-growing economies. Sub-Saharan African trends follow a similar trajectory. (Alaganthiran & Anaba, 2022)show that economic growth, energy consumption, and tourism collectively drive emissions in the region. Their study recommends green policy frameworks, particularly for resource-dependent and oil-exporting countries. A recent strand of literature incorporates globalization and financial development as mediating or moderating variables in the growth-emissions relationship. (Teklie & Yağmur, 2024) and (Espoir, Sunge , & Bannor , 2023) underscore the nonlinear impact of these factors, suggesting that without integration into sustainable policy agendas, globalization and financialization may amplify environmental pressures rather than mitigate them. Taken together, the literature underscores the heterogeneity in the economic growth–emissions nexus across regions and development stages. While some economies exhibit EKC-like behavior, others reveal linear or U-shaped relationships, calling for tailored policy approaches that account for structural, institutional, and energy-related differences.

Hypothesis H2.*Economic growth significantly influences CO_2 emissions in Algeria.*

2.3. Natural Resource Rents- Co2 emissions nexus

The environmental consequences of natural resource dependence, especially in terms of CO_2 emissions, have become a critical area of investigation as countries confront the trade-offs between resource-based development and ecological sustainability. A significant body of empirical literature confirms a positive relationship between natural resource rents and environmental degradation, reinforcing the resource curse and pollution haven hypotheses.(Bekun, Alola, & Sarkodie, 2019), using panel data for 16 EU countries, find that natural resource rents substantially increase CO_2 emissions in the long run. Their study attributes this trend to overreliance on extractive industries and the absence of robust environmental safeguards.Similarly, (Shen, et al., 2021), using provincial data from China, demonstrates that resource rents are directly associated with increased carbon emissions. The findings highlight the urgency for institutional reforms, particularly in resource governance and environmental regulation.At the global level, (Shang, Samour, Abbas, Ali, & Tursoy , 2024) employs Method of Moment Quantile Regression (MMQR) and confirms that ecological quality deteriorates with higher resource rents, especially in countries attracting pollution-intensive industries. Financial inclusion is found to further compound these negative effects, indicating the complex interplay between financial and environmental systems in resource-rich contexts.(Ulucak, Danish, & Ozcan, 2020)observes that while resource rents significantly drive CO_2 emissions in OECD countries, their impact on broader ecological indicators such as carbon and ecological footprints remains statistically insignificant. This suggests a direct but narrowly concentrated environmental impact of extractive activities.(Wang, Vinh Vo , Shahbaz, & Ak, 2020)extends this analysis to G7 countries and finds that the environmental costs of resource rents persist even in advanced economies, despite their efforts to integrate environmental concerns into development agendas. The study emphasizes that globalization and financial development do not offset the carbon-intensive nature of resource exploitation.The importance of institutional quality and green energy alternatives is widely acknowledged. (Szetela, Majewska, Jamroz, Djalilov, & Salahodjaev, 2022)finds that the beneficial effect of renewable energy in reducing emissions is contingent upon governance effectiveness. In resource-dependent economies with weak institutions, renewable efforts often fall short of offsetting extractive-induced emissions.Overall, the literature suggests that natural resource rents, if not managed within a comprehensive sustainability framework, can severely undermine environmental objectives. The call for transitioning toward renewable energy, improving governance standards, and adopting green investment strategies is echoed across studies to ensure that resource wealth translates into long-term ecological resilience.

Hypothesis H3.Natural resource rents significantly influence CO_2 emissions in Algeria.

2.4. Research Gap and Study Contribution

Despite the growing global interest in the relationship between financial inclusion, economic growth, natural resource rents, and environmental degradation, empirical studies remain limited in the specific context of Algeria. Existing literature largely focuses on cross-country panels or major emerging economies, with insufficient attention to North African or hydrocarbon-dependent countries. Furthermore, the interaction between financial inclusion and environmental outcomes is still underexplored at the national level, particularly in resource-rich economies where institutional and economic structures differ markedly. This study aims to fill this gap by providing a country-specific analysis of Algeria, employing updated data and advanced econometric techniques to disentangle the individual and combined effects of financial inclusion, economic growth, and natural resource rents on CO_2 emissions. By doing so, it contributes to a more nuanced understanding of the drivers of environmental degradation in developing, resource-rich contexts and offers policy-relevant insights tailored to Algeria's sustainability challenges.

3. METHODOLOGY

3.1. Data descriptive and variables

In terms of methodology, the study employed a quantitative approach, utilizing both econometric and descriptive techniques to achieve its objectives. The research relied on primary data sourced from Our World in Data. Regarding the scope, the study concentrated on Algeria for the period between 2004 and 2023. It is important to highlight that the annual time series data was converted into biannual data, resulting in 39 observations. This conversion was achieved using cubic interpolation. Table 1 provides a clear explanation for all the factorsincluded in our study

Variable	Acronym	Proxy	Source
CarbonDioxide	CO_2	CarbonDioxide	Our World in Data
Financial iclusion	FI1	- ATMs (per 100,000 adults) - Commercial bank branches (per 100,000 adults) - Borrowers from	Our World in Data

		commercial banks (per 1,000 adults)	
Economic Growth	EG	GDP growth (annual%)	Our World in Data
Natural Resource Rents	NRR	Total Natural Resource Rents (of GDP %)	Our World in Data

Table 1. Description of variables

3. 2. Model specification

The empirical model used to investigate the relationship between Financial inclusion, economic growth and natural resource rents on Co2 emissionsis represented as follows:

$$CO2_t = C + \beta_1 FI_t + \beta_2 EG_t + \beta_3 NRR_t + \epsilon t$$

The proxies for all variables used in the analysis have been previously defined, with the exception of the error term ϵt. The coefficients $\beta 1$,$\beta 2$ and $\beta 3$ quantify the effect of the respective Financial inclusion, economic growth and natural resource rents.

3.3. Cointegration- autoregressive distributed lag bound testing procedure

The study utilizes the Autoregressive Distributed Lag (ARDL) bounds testing approach to explore cointegration and assess the short- and long-term effects of selected independent variables on Co2 emissions. The ARDL model, originally developed by Pesaran and Shin (1998) and further refined by Pesaran et al. (2001), is chosen for its advantages over alternative cointegration methods, such as fully modified OLS and Johansen. One of the key strengths of the ARDL approach is its flexibility in handling variables that are either stationary at level I(0), first difference I(1), or a combination of both. Additionally, it allows for different lag lengths for each variable and performs well even with small sample sizes.

The bounds testing procedure is employed to examine the long-term relationship among the variables using an F-test. The null hypothesis assumes the absence of a long-run relationship among the variables, while the alternative hypothesis proposes the presence of such a relationship, as defined below:

- Null Hypothesis $H_0 : \beta_1 = \beta_2 = 0$,
- Alternative Hypothesis $H_0 : \beta_1 = \beta_2 = 0$ (presence of a long-run relationship).

Two critical bounds are used in the analysis: the upper bound I(1) and the lower bound I(0) The results of the F-test are interpreted as follows:

- If the F-statistic exceeds the upper bound I(1), it confirms the existence of a long-term relationship (cointegration) among the variables.
- If the F-statistic falls below the lower bound I(0), it suggests no cointegration.
- If the F-statistic lies between the upper and lower bounds, the result is deemed inconclusive.

This method provides a robust framework for assessing both short-term dynamics and long-term equilibrium relationships in the model.

4. Empirical results

4.1. Data description

The descriptive statistics for the variables—CO_2 emissions (CO2), financial inclusion (FI), economic growth (EG), and natural resource rents (NRR)—indicate varied patterns across the dataset. CO2 has a mean of 143.65 with moderate dispersion (standard deviation of 28.88), slight negative skewness (−0.08), and a platykurtic distribution (kurtosis = 1.53), suggesting normality according to the Jarque–Bera test (p = 0.167). FI shows greater variability (std. dev. = 1.63), strong negative skewness (−1.03), and a near-normal kurtosis (3.02), but is not normally distributed (p = 0.031). EG presents a low mean (0.0266), high negative skewness (−1.85), leptokurtic behavior (kurtosis = 7.19), and clear deviation from normality (p = 0.0000). NRR, with a mean of 0.2373 and low dispersion (std. dev. = 0.0631), is nearly symmetric (skewness = −0.10), slightly platykurtic (kurtosis = 2.08), and normally distributed (p = 0.488). Overall, while CO2 and NRR conform to normality assumptions, FI and especially EG demonstrate non-normal characteristics that may influence econometric modeling.

	CO2	FI	EG	NRR
Mean	143.6502	0.021733	0.026550	0.237274
Median	145.3503	0.536153	0.030589	0.239954

Maximum	184.5600	1.834860	0.054000	0.341900
Minimum	91.71000	-3.746319	-0.050000	0.128200
Std. Dev.	28.87895	1.632949	0.020706	0.063052
Skewness	-0.087527	-1.032477	-1.851102	-0.100447
Kurtosis	1.526864	3.020832	7.187823	2.081531
Jarque-Bera	3.576257	6.929757	50.77179	1.436408
Probability	0.167273	0.031277	0.000000	0.487627
Observations	39	39	39	39

Table2. Descriptive statistics

4.2. Unit root test

In statistical terms, a time series has a unit root if it follows a random walk, meaning that shocks to the series have a permanent effect. This implies that the series does not revert to a long-term mean and that its variance increases over time (Gujarati, 2011). To test for the presence of a unit root, the study employed the Augmented Dickey-Fuller (ADF) test. The ADF test is crucial for confirming the stationarity of the data, which in turn supports the application of the ARDL method to investigate both short-term dynamics and long-term relationships among economic variables. This test was conducted at both the level I(0) and first difference I(1) stages, as shown in Table 3. The results indicate that all variables become stationary at their first difference. Given this outcome, where the factors are integrated at I(0) and I(1), the ARDL method is appropriate for further analysis.

Test / variable	Co2	FI	EG	NRR
At Level				
With constant	-1.5356 (0.5613)	-3.8137 (0.0131)	-3.5356 (0.0184)	-1.4840 (0.5197)
With constant & trend	-1.8949 (0.6075)	-3.0014 (0.1635)	-3.6103 (0.0560)	-1.9463 (0.5918)
Without constant & trend	2.3067 (0.9923)	-2.2423 (0.0275)	-1.9638 (0.0496)	-0.4977 (0.4870)
At First Difference				
With constant	-6.3604 (0.0001)	-4.0358 (0.0070)	-6.5034 (0.0000)	-4.2349 (0.0046)

With constant & trend	-3.7488 (0.0468)	-6.0798 (0.0006)	-6.5175 (0.0003)	-4.0978 (0.0253)
Without constant & trend	-0.5276 (0.0471)	-3.0107 (0.0049)	-6.6972 (0.0000)	-4.3288 (0.0002)
Order	I(1)	I(1)	I(0)	I(1)

Table 3. Unit root test results: ADF

4.3. Lag length selection

For lag selection we depended on the value of akaike information criterion (AIC): (AKAIKE, 1974)

$$AIC= \hat{\sigma}^2 \exp\left[2\left(\frac{p+q}{N}\right)\right]$$

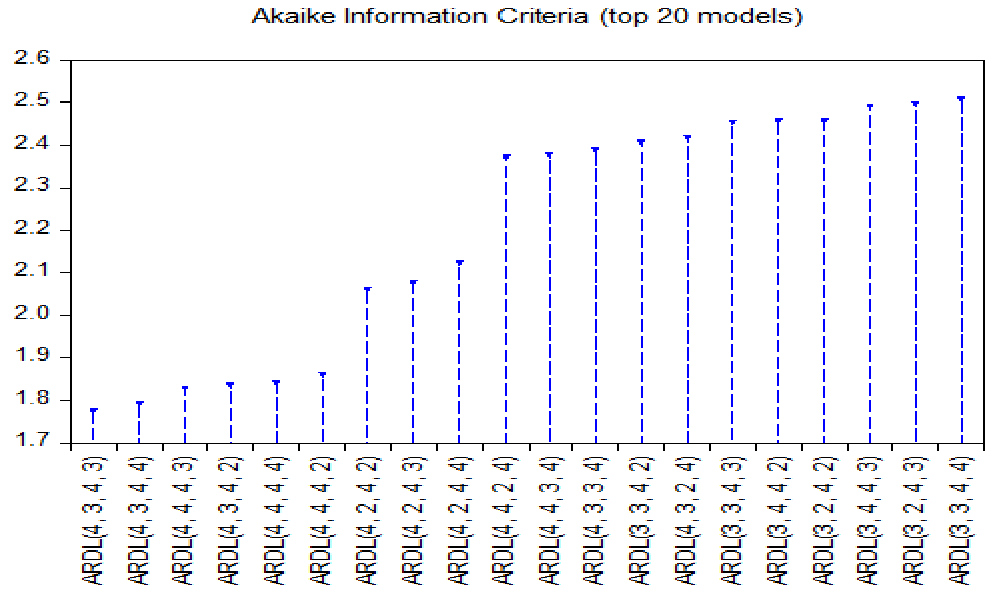

Fig.2.Lag order selection criteria results

The results presented in Figure 1 indicate the selection of an ARDL model with lag lengths (4,3,4,3). To analyze the long-term relationships and short-term dynamics among the variables, the ARDL model can be expressed as follows:

$$CO2_t = C_0 + \sum_{i=1}^{4} \propto_1 \Delta\, CO2_{t-1} + \sum_{i=1}^{3} \propto_2 \Delta\, FI_{t-1} + \sum_{i=1}^{4} \propto_3 \Delta\, EG_{t-1} + \sum_{i=1}^{3} \propto_4 \Delta\, NRR_{t-1} + \beta_1 CO2_{t-1} + \beta_2\, FI_{t-1} + \beta_3 EG_{t-1} + \beta_4 NRR_{t-1} + \varepsilon_t$$

Where: Δ denotes the difference operator, C_0 is the intercept term, $\alpha_1, \alpha_2, \alpha_3$ are the short-run coefficients associated with the changes in the variables, β1,β2,β3 are the long-run coefficients associated with the lagged levels of the variables, ϵt represents the error term.

4.4. Bounds testing for cointegration

The bounds testing analysis evaluates the long-run relationship between the Carbon Dioxide(CO_2) and financial inclusion, economic growth and Natural Resource Rents. As presented in Table 4, the results of the bounds testing indicate that, at a 5% significance level, the computed F-statistic of 5.363373 exceeds the upper critical bound value of 3.67. This outcome signifies the presence of cointegration among the selected variables.

Given this evidence of a long-run relationship, we can proceed to estimate the long-term association between Carbon Dioxide (CO_2) and financial inclusion, economic growth and Natural Resource Rents.The selection of the ARDL model, specifically ARDL(4,3,4,3), is based on the Akaike Information Criterion (AIC), which aids in determining the model that best fits the data while penalizing for complexity.

This analysis underscores the significance of financial inclusion, economic growth and Natural Resource Rents in influencing Carbon Dioxideover the long term, providing a foundation for further exploration of the dynamics involved in this relationship.

Test statistics	Value	Level	Critical values	
			I(0)	I(1)
F-statistics	5.363373	10%	2.37	3.27
K	3	5%	2.79	3.67
		1%	3.65	4.66

Table 4. Bound test for cointegration relationship

4.5. Long-run estimation

The ARDL (4,3,4,3) model, selected using the Akaike Information Criterion (AIC), examines the influence of financial inclusion (FI), economic growth (EG), and natural resource rents (NRR) on carbon dioxide (CO_2) emissions. The estimation results reveal that financial inclusion has a statistically significant and positive effect on CO_2 emissions, with a coefficient of 13.59 ($p = 0.0003$). This suggests that increased access to financial services may lead to greater industrial activity and energy use, thereby intensifying environmental degradation. Economic growth also demonstrates a positive and significant relationship with CO_2 emissions, with a coefficient of 528.95 ($p = 0.0327$), which aligns with the Environmental Kuznets Curve (EKC) hypothesis in its early stages—where growth initially leads to environmental harm. In contrast, natural resource rents exhibit a significant positive relationship between natural resource rents (NRR) and CO_2 emissions in Algeria, with a coefficient of 189.92 ($p<0.01$). This finding aligns with conventional environmental-economic theory and the "resource curse" hypothesis, indicating that Algeria's dependence on hydrocarbon extraction and related industrial activities has led to increased carbon emissions. The results suggest that resource revenues are primarily being channeled into expanding fossil fuel infrastructure rather than sustainable projects, exacerbated by insufficient environmental governance frameworks. Collectively, these findings emphasize the critical need for policies that encourage responsible resource use, green financial frameworks, and growth strategies that align with environmental sustainability.

ARDL (4,3,4,4) selected based on AIC dependent variable = CO_2				
Variable	Coefficient	SE	t-statistic	Probability value
FI	13.58948	3.346901	4.060317	0.0008***
EG	528.9530	227.5435	2.324624	0.0327**
NRR	189.9167	59.89070	3.171054	0.0056***
Constant	184.7472	16.70038	11.06245	0.0000***
Note: *** denote significance at 1% level, ** denote significance at 5% level respectively				

Table 5. long-runestimates

4.6. Short-run estimation

In the short run, the lagged change in CO_2 emissions (ΔCO_{2t-3}) exerts a significant and positive effect on current CO_2 emissions, with a coefficient of 0.3471 and a p-value of 0.0000, indicating strong persistence in emission levels over time. Financial inclusion (ΔFI_{t-2}) also shows a significant and positive impact on CO_2 emissions, with a coefficient of 2.6339 ($p = 0.0004$), implying that increased financial access accelerates activities that raise carbon emissions in the short term. Similarly, economic growth (ΔEG_{t-3}) has a substantial and statistically significant negative effect on CO_2 emissions, with a coefficient of -103.8042 ($p = 0.0000$), which may reflect temporary shifts toward efficiency or cleaner production during the period analyzed. However, the effect of natural resource rents (ΔNRR_{t-3}) on emissions is negative (-28.6035) but statistically insignificant (p = 0.0812), suggesting that in the short run, the environmental benefits of natural resource revenues are limited or not consistently realized. The error correction term (ECM_{t-1}) is negative and highly significant (-0.0683, p = 0.0000), confirming the presence of a stable long-run relationship among the variables and indicating that deviations from the long-term equilibrium are corrected at a speed of 6.8% per period. The high R^2 (0.9987) and adjusted R^2 (0.9817) values demonstrate a strong model fit, while the Durbin-Watson statistic (2.5786) suggests no serious autocorrelation issues.

ARDL (4,3,4,3) selected based on AIC dependent variable = CO2				
Variable	Coefficient	SE	t-statistic	Probability value
$\Delta CO2_{t-3}$	0.347116	0.053833	6.44802	0.0000
ΔFI_{t-2}	2.633900	0.601273	0	0.0004
ΔEG_{t-3}	-103.8402	11.52872	4.38054	0.0000
ΔNRR_{t-3}	-28.60348	15.42899	1	0.0812
ECM_{t-1}	-0.068828	0.011959	-	0.0000
R^2	0.988712		9.007092	
Adjested	0.981723		-	
R^2	2.578564		1.853879	
DW			-	
			5.755581	
* p-value incompatible with t-Bounds distribution.				

Table 6. Results of short-run dynamic model

4.7. Diagnostic tests results

Finally, we conducted several diagnostic tests to validate our findings. As shown in Table 7, at the 5% significance level, our model demonstrates that it is free from serial correlation, heteroscedasticity, and functional misspecification. Additionally, the Jarque-Bera statistic indicates that the residuals of our model are normally distributed.These diagnostic checks reinforce the robustness of our model and the reliability of our findings regarding the long-run relationship between Carbon Dioxide (CO_2) and financial inclusion, economic growth and Natural Resource Rents

Specification	F-statistics	Probability value
Breusch-Godfrey LM test	2.152373	0.1617
Breusch-Pagan (hetroscedasticity)	1.267833	0.3151
Jarque-Bera (normality)	0.340200	0.843580
Ramsey RESET	3.070217	0.0989

Table 7. Diagnostic tests

Similarly, the results from the CUSUM and CUSUMSQ plots, illustrated in Figures 2 and 3 respectively, indicate that the model is stable. The CUSUM lines remain within the critical boundaries at the 5% significance level, suggesting that there are no structural breaks in the model over the sample period.

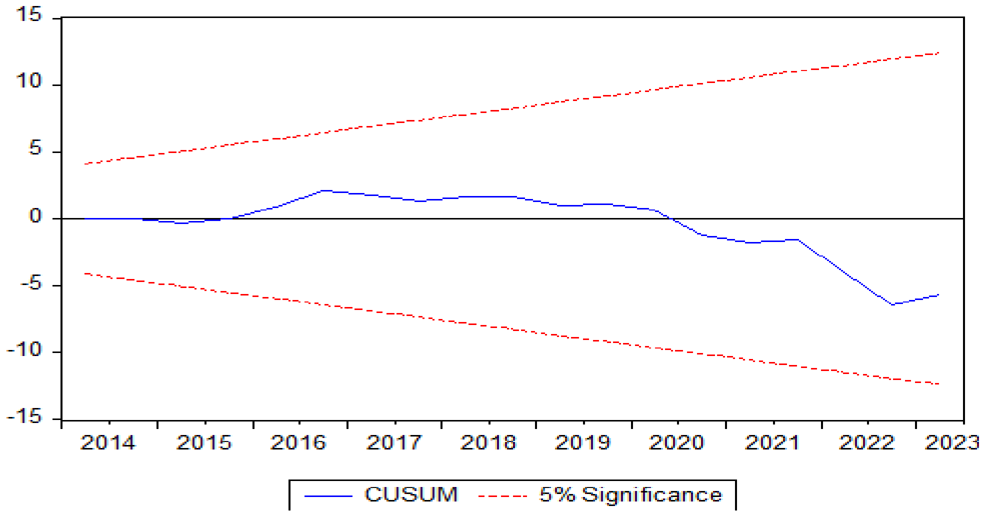

Fig.3. Plots of CUSUM

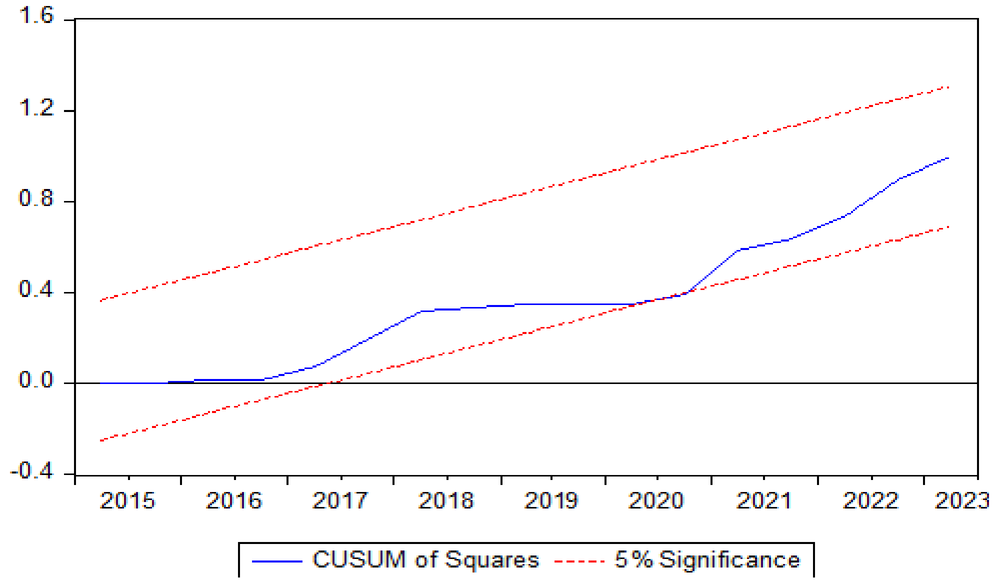

Fig.4. CUSUM of squares

5. Conclusion

This study examined the dynamic interplay between financial inclusion, economic growth, natural resource rents, and CO_2 emissions in Algeria from 2004 to 2023, employing an ARDL cointegration framework. The findings reveal critical insights into the environmental consequences of Algeria's economic and financial development, offering policy-relevant implications for sustainable growth in resource-dependent economies.

Key Findings:

1.Financial Inclusion (FI) significantly exacerbates CO_2 emissions in both the short and long run, underscoring the carbon-intensive repercussions of expanding financial access without complementary green policies. This validates *H1*, confirming that financial inclusion in Algeria drives carbon-intensive economic activities. This aligns with emerging economy studies(Ullah, Ali, Ali Shah, & Ehsan , 2022)(Ahmad, et al., 2022), highlighting Algeria's need for policy integration.

2.Economic Growth (EG) exhibits a positive long-run relationship with emissions (β = 528.95, p = 0.0327), supporting the early-phase Environmental Kuznets Curve (EKC) hypothesis. However, the short-run negative coefficient suggests transient efficiency gains, highlighting the need for structural shifts toward sustainable industrialization.The mixed results mirror the literature's inconclusive findings on EKC validity (Espoir, Sunge , & Bannor , 2023) (Mikayilov, Galeotti, & Hasanov, 2018), emphasizing Algeria's transitional growth phase.

3.Natural Resource Rents (NRR) demonstrate a significant positive impact on emissions (β = 189.92, $p < 0.01$), reinforcing the "resource curse" hypothesis. This underscores Algeria's reliance on hydrocarbon extraction and the need to redirect rents toward sustainable infrastructure. This validates *H3*, confirming the "resource curse" hypothesis (Bekun, Alola, & Sarkodie, 2019). Algeria's hydrocarbon dependence directly fuels emissions due to: Carbon-intensive extraction practices ; Limited reinvestment in green infrastructure.

Theoretical Contributions:

- Algeria's growth trajectory mirrors early-phase EKC dynamics, but the absence of decoupling highlights the urgency of policy interventions to accelerate the transition to cleaner growth.
- While FI fosters economic inclusion, its environmental costs necessitate integrated green finance frameworks.
- The positive NRR-emissions linkage challenges optimistic views of resource-driven sustainability, emphasizing governance gaps in revenue allocation.

Policy Recommendations

- Green Financial Policies: Mandate environmental criteria for credit allocation (e.g., preferential loans for renewables) and establish a national green banking framework.
- Low-Carbon Growth Strategies: Invest in solar and wind energy infrastructure, coupled with carbon pricing mechanisms to internalize environmental costs.
- Sustainable Resource Management: Create a sovereign wealth fund for renewable energy projects and enforce stricter environmental regulations on extractive industries.

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