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Original Article

Renewable Investments: A Catalyst For Sustainable Development In Nigeria

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Abstract - *This study examined whether renewable energy investment, renewable agriculture and forestry investment improve environmental sustainability in Nigeria. Using annual data for 2000–2023, carbon emissions were modelled as a function of renewable energy investment, renewable agriculture and forestry investment, and gross domestic product. After descriptive analysis, correlation analysis, Augmented Dickey–Fuller unit-root testing and Johansen cointegration testing, long-run coefficients are estimated with Fully Modified Ordinary Least Squares, while pairwise Granger-causality tests assessed short-run predictive direction. The results showed that renewable energy investment had a negative and statistically significant relationship with carbon emissions ($\beta = -2.958$, $p = 0.0011$), renewable agriculture and forestry investment had a negative but statistically insignificant relationship ($\beta = -8.58\times10^{-6}$, $p = 0.2068$), and GDP had a positive and significant influence on emissions ($\beta = 7.50\times10^{-11}$, $p = 0.0149$). No pairwise Granger-causal relationship with carbon emissions was detected at the 5% level. The study contributed investment-based evidence that distinguishes energy investment from agriculture and forestry investment, rather than treating renewable activity as a single consumption indicator. The findings support sustained renewable-energy finance, stronger measurement and targeting of climate-smart agricultural investment, cleaner industrial production, and transition policies that distribute benefits across underserved communities.*

Keywords - *Carbon Emissions, Fmols, Nigeria, Renewable Agriculture Investment, Renewable Energy Investment, Sustainable Development.*

1. Introduction

Energy access, economic transformation and climate stability are tightly connected in Nigeria. The country must expand modern energy services for households and firms while reducing dependence on carbon-intensive fuels and self-generation. This tension is especially important because unreliable grid supply has historically pushed households and businesses toward petrol and diesel generators, while the national development strategy simultaneously requires industrial expansion, agricultural modernization and wider electricity access. The policy challenge is therefore not simply to increase energy supply, but to determine whether investment directed toward renewable activities is already associated with measurable environmental gains.

Nigeria possesses substantial solar, hydropower, wind and biomass potential, yet deployment remains below the scale required for universal access and deep decarbonization. The International Renewable Energy Agency serves as Nigeria's roadmap, which indicates that a renewable-intensive transition can provide energy services at system-wide investment costs that are competitive with a conventional pathway, while requiring major sustained capital mobilization [1]. In practical terms, the scale of the transition is visible in the USD 750 million Distributed Access through Renewable Energy Scale-up programme, which targets new or improved electricity access for more than 17.5 million people through distributed renewable-energy solutions [2]. These initiatives create a strong policy expectation that renewable investment should reduce emissions; however, the empirical relationship is not automatic because investment may be delayed, poorly targeted, constrained by grid bottlenecks or offset by simultaneous expansion in fossil-fuel-intensive activity.

The empirical problem is that much of the Nigerian literature measures renewable energy through consumption shares, installed capacity or aggregate energy use rather than actual investment flows. This distinction matters. Consumption indicators describe energy use after infrastructure is operational, whereas investment captures financial commitment before, during and after deployment. The environmental effect of investment may therefore depend on implementation lags, technology composition, transmission readiness, governance quality and the extent to which new renewable capacity displaces rather than merely supplements fossil-fuel use. Existing Nigerian evidence also gives greater attention to the energy–growth–emissions nexus than to the comparative environmental effects of renewable energy investment and renewable agriculture and forestry investment.

Recent studies illustrate this gap. [3] documented a dynamic relationship among renewable energy consumption, carbon emissions and economic growth in Nigeria, while [4] showed that financial development can shape renewable-energy consumption. [5] used broader evidence and found that renewable-energy investment can reduce carbon emissions through scale and structural channels. According to [6], it was reported that the emission-reducing effects of renewable energy investment and green technological innovation across Chinese provinces. In the Nigerian agricultural context, [7] found that energy use, agricultural trade and productivity have heterogeneous effects across the conditional distribution of emissions. These studies are informative, but they do not directly answer whether distinct categories of renewable investment in Nigeria have different long-run relationships with carbon emissions within one coherent investment-based model.

The central research gap is therefore threefold. First, evidence for Nigeria is dominated by renewable-energy consumption rather than investment, leaving the financing–environment link underexamined. Second, energy and agriculture-related renewable investments are rarely separated, although their implementation channels and emission effects differ. Third, the coexistence of a long-run investment–emissions relationship and the absence or presence of short-run predictive causality is seldom evaluated jointly. The present study addresses these gaps by estimating the long-run effects of renewable energy investment and renewable agriculture and forestry investment on carbon emissions, controlling for GDP, and then examining causal direction over 2000–2023.

The originality of the study lies in its disaggregated investment perspective. Unlike studies that treat renewable energy consumption as the principal explanatory variable [3] or focus on financial sector determinants of renewable energy uptake [4], this study compares two investment channels, which are renewable energy and renewable agriculture/forestry, against a common environmental outcome. It also combines cointegration-based long-run estimation with causality testing, allowing a distinction between statistically significant long-run effects and short-run predictive direction. The comparison is policy-relevant because a significant energy-investment coefficient alongside an insignificant agriculture-investment coefficient indicates that investment categories should not be assumed to produce equal or immediate mitigation returns.

Accordingly, the study has three objectives: (1) to estimate the effect of renewable energy investment on carbon emissions in Nigeria; (2) to investigate the effect of renewable agriculture and forestry investment on carbon emissions in Nigeria; and (3) to determine whether renewable investment and carbon emissions exhibit predictive causal relationships. The corresponding research questions are: What is the effect of renewable energy investment on carbon emissions? What is the influence of renewable agriculture and forestry investment on carbon emissions? Does a predictive causal relationship exist between renewable investment and carbon emissions?

The scope is Nigeria over the period 2000–2023. Carbon emissions represent the environmental dimension of sustainable development. Consequently, the study does not claim that a single emissions indicator captures all economic and social dimensions of sustainability. This boundary is important for interpreting the findings and for identifying future research needs concerning energy access, employment, health, gender inclusion, affordability and distributional justice.

2. Literature Review

2.1. Conceptual and Theoretical Foundations

Renewable energy investment refers to financial resources committed to the development, installation, upgrading and maintenance of energy systems based on replenishable sources such as solar, wind and hydropower. Its environmental logic rests on displacement [16]. It is important to state that emissions decline when low-carbon generation substitutes for fossil-fuel-based generation or polluting self-generation. Investment can also create indirect effects through learning, cost reduction, local supply chains and improved energy security. Nevertheless, the effect may be weak when renewable capacity is not connected, when storage and transmission are inadequate, or when rising energy demand causes renewable generation to supplement rather than replace fossil fuels.

According to [17], renewable agriculture and forestry investment covers financial commitments to sustainable farming, efficient irrigation, agroforestry, renewable-powered processing, land restoration and related technologies intended to raise productivity while conserving environmental assets. The emissions channel is more complex than in electricity generation because agriculture produces carbon dioxide, methane and nitrous oxide through multiple processes. A project may improve resilience or productivity without producing an immediate decline in aggregate carbon emissions. Measurement quality is therefore particularly important.

The study is anchored in sustainable development theory, derived from the Brundtland conception of development that meets present needs without compromising future generations [8]. In this framework, renewable investment is expected to expand productive capacity while preserving environmental capital. The theory predicts a negative relationship between effective renewable investment and carbon emissions. The GDP control is informed by the environmental Kuznets curve debate, which explains that, at lower and middle stages of development, economic expansion can raise emissions through industrialization, transport demand and fossil-energy use; at higher income and institutional capacity, structural change and cleaner technologies may weaken or reverse the relationship. For a fossil-fuel-dependent economy, a positive GDP coefficient is therefore plausible.

2.2. Structured Review Strategy and Evidence Synthesis

To strengthen the analytical background, the literature review followed a structured narrative approach. Searches were organized around combinations of the terms' renewable energy investment, renewable energy consumption, carbon emissions, sustainable development, green finance, agriculture, Nigeria and sub-Saharan Africa. Priority was given to peer-reviewed studies published from 2021 onward, while older foundational works were retained only where required for theory or econometric method. Institutional reports were used selectively for policy context, project finance and national transition data, not as substitutes for peer-reviewed empirical evidence.

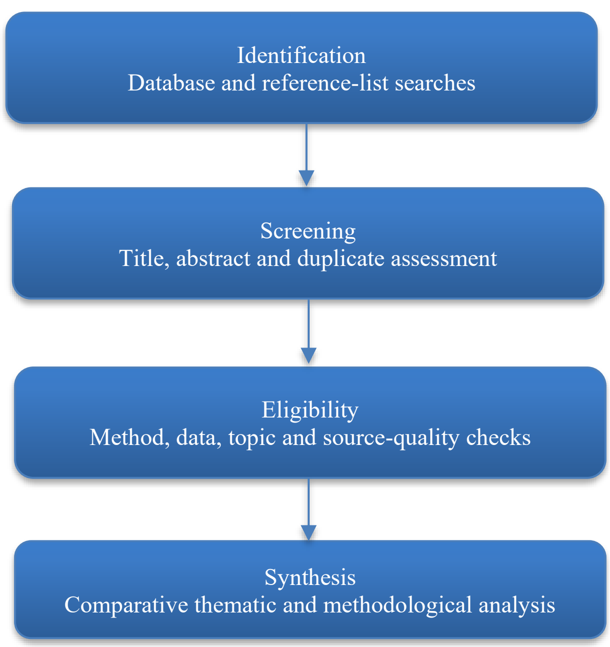

Fig. 1 Structured review and evidence-synthesis process.

Studies were included when they: (i) examined renewable energy, green investment, agriculture-related energy use or emissions; (ii) reported an identifiable empirical method and data period; (iii) addressed Nigeria, comparable African settings or directly relevant international evidence; and (iv) contributed to the investment–emissions, energy–growth, or agriculture–emissions relationship. Purely promotional web material, duplicate records, studies without a transparent method and sources with unverifiable bibliographic details were excluded. Evidence was synthesized comparatively by geography, proxy choice, method and direction of findings rather than as an article-by-article catalogue.

2.3. Comparative Empirical Evidence

Evidence from Nigeria and comparable settings is mixed because studies use different proxies and methods. The study of [3] linked renewable energy consumption, emissions and growth in Nigeria, demonstrating the importance of modelling the variables dynamically. [4] shifted attention toward the financial conditions supporting renewable-energy consumption and found that financial development matters for the transition. These studies support the broader proposition that finance and renewable energy are connected, but neither directly compares separate renewable investment categories against carbon emissions.

International investment-based evidence is more directly comparable to the present study. [5] reported that renewable-energy investment can reduce carbon dioxide emissions through scale and structural effects. [6] found that renewable-energy investment and green technological innovation reduced emissions in a provincial Chinese panel. [9] Likewise, connected green finance, technological innovation and renewable energy with sustainable-development outcomes. The common implication is that investment quality, technological composition and financial architecture jointly determine environmental returns.

Agriculture-related evidence is less uniform. [7], Using quantile regression for Nigeria, found heterogeneous emission effects from energy consumption, agricultural trade and productivity. This suggests that agricultural transition variables can behave differently across the emissions distribution and should not be assumed to mirror electricity-sector effects. The present study's insignificant coefficient for renewable agriculture and forestry investment is therefore not interpreted as proof that sustainable agriculture is environmentally ineffective; rather, it may reflect scale, lag, measurement aggregation and offsetting land-use effects.

Recent Nigerian evidence also continues to show that fossil-intensive growth can raise emissions. [10] found a long-run relationship among non-renewable energy consumption, economic growth and carbon emissions using ARDL methods. [11] examined emissions, foreign direct investment and economic growth with multivariate causality methods. Taken together, the literature supports the inclusion of GDP as a control and cautions against interpreting economic expansion as environmentally neutral.

Table 1. Comparative position of the study within recent literature

Study	Setting / method	Core finding	Gap relative to the present study
Yusuf [3]	Nigeria: dynamic time-series	The existence of environmental Kuznets curve hypothesis is applicable in the Nigerian economy both in the short-run and long-run.	There is a narrow focus on carbon emissions as the sole indicator of environmental quality.
Dimnwobi et al. [4]	Nigeria; time-series	Financial development shapes renewable-energy consumption.	Focuses on determinants of consumption, not the emission effects of investment.
Yang et al. [5]	Cross-country/structural channels	Renewable investment can reduce CO_2 through scale and structural effects.	Not Nigeria-specific; no agriculture-investment comparison.
Fang [6]	China; provincial GMM	Renewable investment and green innovation reduce emissions.	Different institutional setting and panel design.
Edoja et al. [7]	Nigeria; quantile regression	Agricultural trade, productivity and energy effects vary across emission quantiles.	Does not isolate renewable agriculture/forestry investment.
Present study	Nigeria; FMOLS + Granger, 2000–2023	REI significantly lowers emissions; RAI is negative but insignificant; GDP raises emissions; no short-run causality detected.	Direct disaggregated investment comparison.

2.4. Policy and Stakeholder Context

Nigeria's renewable transition is shaped by federal policy, regulators, development-finance institutions, private developers, electricity distribution companies, state governments and host communities. The IRENA roadmap identifies a large-scale transition pathway and substantial investment requirements [1]. The DARES programme illustrates a blended implementation model in which public and concessional finance are intended to catalyze private-sector delivery of mini-grids and stand-alone solar systems [2]. This model is relevant to the study because the environmental effectiveness of investment depends on whether financial commitments translate into operating assets that displace polluting generation.

Stakeholder incentives are not identical. Investors seek predictable tariffs, currency-risk management and bankable offtake arrangements. However, communities prioritize affordability, reliability, livelihoods and local participation while the government seeks energy access, industrial growth and climate commitments. Furthermore, farmers require technologies that are affordable, maintainable and adapted to local production systems. These perspectives explain why aggregate investment may not produce immediate causality in annual national data. Implementation delays, policy uncertainty, foreign-exchange risk, grid constraints and uneven technical capacity can weaken the transmission from finance to measured emissions.

Equitable benefit distribution is also central. Renewable projects can reproduce existing inequalities if capital subsidies benefit only bankable customers, if land acquisition excludes local users, or if women-led and low-income enterprises cannot afford productive-use equipment. Conversely, distributed energy can improve inclusion when programme design explicitly targets underserved households and micro, small and medium-sized enterprises. The DARES design includes inclusion objectives and productive-use targets, illustrating how environmental investment can be linked to broader development outcomes [2].

Table 2. Selected Nigerian renewable-investment and transition context

Initiative/policy context	Scale or target	Relevance to investment–sustainability link
IRENA Renewable Energy Roadmap for Nigeria [1]	Transition scenarios to 2050; large annual capital requirement	Shows that deep renewable uptake requires sustained, system-wide investment and grid/end-use coordination.
Nigeria DARES [2]	USD 750 million; >17.5 million people targeted for new/improved access	Demonstrates blended public finance and private delivery for distributed renewable energy.

Nigeria Electrification Project legacy [2]	125 mini-grids; >1 million solar home systems reported by programme source	Provides implementation precedent and highlights access, jobs and displacement of polluting self-generation.
Energy Transition investment portfolio [12]	Initial USD 23 billion opportunity portfolio; about USD 17 billion private-sector funding need	Shows the financing gap and the importance of private capital mobilisation across transition sectors.

3. Materials and Methods

3.1. Research Design, Scope and Data

The study adopts an ex post facto longitudinal design based on annual secondary data for Nigeria from 2000 to 2023. The design is appropriate because the variables have already occurred and cannot be experimentally manipulated. The unit of analysis is the Nigerian economy observed annually.

The dependent variable is Carbon Emissions (CAEM). The explanatory variables are Renewable Energy Investment (REI) and Renewable Agriculture and Forestry Investment (RAI), while Gross Domestic Product (GDP) is included as a control for the scale of economic activity.

Data were compiled from publicly available secondary sources. GDP data were obtained from the Central Bank of Nigeria statistical publications, renewable-investment series from the International Renewable Energy Agency data resources, and carbon-emissions data from the World Development Indicators.

For reproducibility, the analytical dataset should be archived with the final submission as supplementary material, including variable names, units, transformations and retrieval dates. This requirement is particularly important because the magnitude interpretation of investment coefficients depends on the original currency and scaling of each series.

3.2. Model Specification and Hypotheses

The functional relationship is specified as SDVT = f(RI), where sustainable development is operationalized by carbon emissions and renewable investment is disaggregated into renewable energy investment and renewable agriculture and forestry investment. The estimable model is:

$$CAEM_t = \beta_0 + \beta_1 REI_t + \beta_2 RAI_t + \beta_3 GDP_t + \varepsilon_t \qquad (1)$$

The a priori expectations are $\beta_1 < 0$ and $\beta_2 < 0$. GDP may be positive where growth remains carbon-intensive. The null hypotheses are: H_{01}: REI has no significant negative effect on CAEM; H_{02}: RAI has no significant negative effect on CAEM; and H_{03}: renewable investment has no significant Granger-causal relationship with CAEM.

3.3. Analytical Procedure and Data Synthesis

Analysis proceeds in three stages. First, descriptive statistics and Pearson correlation coefficients summarize distributional properties and bivariate association. Second, Augmented Dickey–Fuller tests assess integration order, followed by Johansen trace and maximum-eigenvalue tests for long-run cointegration. Third, the long-run coefficients are estimated with Fully Modified Ordinary Least Squares (FMOLS), and pairwise Granger-causality tests evaluate short-run predictive direction.

FMOLS is appropriate when variables are integrated and cointegrated because it modifies ordinary least squares to correct for endogeneity and serial-correlation effects associated with cointegrating regressions [13]. The Johansen procedure is used to test the number of cointegrating vectors [14]. The Granger test is interpreted strictly as predictive causality: rejection indicates that lagged values of one series add predictive information for another; failure to reject does not establish the absence of structural, technological or policy causation.

Several safeguards guide interpretation. Correlation coefficients are not treated as causal evidence. The high correlations among CAEM, GDP and RAI are acknowledged as a potential source of coefficient instability in a small sample. Statistical significance is considered together with sign, magnitude, theory and comparative evidence. Because the sample contains 24 annual observations, the study avoids over-parameterization and treats causal non-rejection cautiously.

3.4. Ethics, Integrity and Conflict of Interest

The study uses aggregate, publicly available secondary data and does not involve human participants, personal data, clinical intervention or animal subjects. Therefore, formal human-subject ethical approval is not applicable. Nevertheless, research integrity obligations remain. Data sources, transformations and analytical decisions were documented transparently, and results were not selectively reported.

The authors declare that citation selection is based on relevance and evidential quality rather than author, journal or institutional affiliation. No citation is added solely to influence citation metrics. Any author self-citations or journal self-citations that are not indispensable to the argument are removed before submission in accordance with the journal’s policy. The authors also disclose any financial or non-financial conflict of interest and identify that they do not receive any funding source.

4. Results and Discussion

4.1. Descriptive Statistics

CAEM is approximately symmetric, while REI shows mild positive skewness. RAI is more strongly right-skewed, reflecting the concentration of larger observations in some years. GDP is mildly left-skewed.

The Jarque–Bera probabilities exceed 0.05 for all variables, so normality is not rejected at the 5% level. Given the small sample, these diagnostics are treated as descriptive rather than definitive evidence of distributional adequacy.

Table 3. Descriptive statistics. Source: Authors' computation from study data

Statistic	CAEM	REI	RAI	GDP
Mean	69.76458	78.20167	422,913.4	3.90E+11
Median	68.55500	78.08500	285,784.6	4.15E+11
Skewness	−0.014257	0.444123	1.126083	−0.367894
Kurtosis	1.266207	2.729033	3.128723	1.701095
Jarque–Bera	3.006853	0.862406	5.088825	2.228538
Probability	0.222367	0.649727	0.078519	0.328155
Observations	24	24	24	24

4.2. Correlation Analysis

The bivariate results show a strong negative association between REI and CAEM (r = −0.742) and strong positive associations of CAEM with RAI (r = 0.810) and GDP (r = 0.921). The positive simple correlation between RAI and CAEM contrasts with the negative FMOLS coefficient reported later, indicating that the bivariate association is confounded by common trends and covariation with GDP. The high GDP–RAI correlation (r = 0.824) also reinforces the need for cautious coefficient interpretation.

Table 4. Pearson correlation matrix. Source: Authors' computation

Variable	CAEM	REI	RAI	GDP
CAEM	1.000	−0.742	0.810	0.921
REI	−0.742	1.000	−0.438	−0.606
RAI	0.810	−0.438	1.000	0.824
GDP	0.921	−0.606	0.824	1.000

4.3. Stationarity and Cointegration

All four series fail to reject the unit-root null at the level but reject it after first differencing at the 5% level. They are therefore treated as I(1), supporting a cointegration test before long-run estimation.

Table 5. ADF unit-root results. Null hypothesis: unit root. Source: Authors' computation

Variable	ADF level	p-value	ADF first difference	p-value	Order
CAEM	−0.9971	0.7366	−4.6978	0.0013	I(1)
REI	−2.5436	0.1188	−5.8932	0.0001	I(1)
RAI	3.5929	1.0000	−3.2386	0.0311	I(1)
GDP	−2.0726	0.2565	−3.0206	0.0405	I(1)

Table 6. Johansen cointegration summary. Source: Authors' computation

Test	Hypothesis	Statistic	5% critical value	p-value	Decision
Trace	None	64.385	47.856	0.0007	Reject
Trace	At most 1	36.222	29.797	0.0079	Reject
Trace	At most 2	14.595	15.495	0.0680	Do not reject
Max-eigen	None	28.163	27.584	0.0421	Reject
Max-eigen	At most 1	21.627	21.132	0.0426	Reject
Max-eigen	At most 2	9.787	14.265	0.2263	Do not reject

Both the trace and maximum-eigenvalue procedures support two cointegrating relationships at the 5% level when interpreted sequentially. This provides evidence of long-run equilibrium relationships among the variables and supports FMOLS estimation.

4.4. FMOLS Estimates

The FMOLS estimates show that renewable energy investment is negatively and significantly associated with carbon emissions (β = −2.958, p = 0.0011). The direction is consistent with the substitution logic of sustainable development theory and with investment-based evidence that renewable capital can reduce emissions when it changes the scale and structure of energy supply [5]. It also agrees with [6], who found emission-reducing effects from renewable investment and green innovation, although the institutional setting and estimator differ.

Table 7. FMOLS long-run estimates; dependent variable: CAEM—source: Authors' computation

Variable	Coefficient	Std. error	t-statistic	p-value
REI	−2.958165	0.766651	−3.858556	0.0011
RAI	−8.58E−06	6.56E−06	−1.306949	0.2068
GDP	7.50E−11	2.80E−11	2.676240	0.0149
Constant	268.9594	65.20041	4.125118	0.0006
R^2	0.899967			
Adjusted R^2	0.884173			

The principal contribution is not a claim that the coefficient is universally superior to every state-of-the-art estimator or project. Rather, the result provides a stronger and more policy-specific signal than consumption-only models for the question addressed here: it directly links an investment measure to emissions while controlling for GDP and correcting the cointegrating regression for endogeneity and serial-correlation bias. Compared with Nigerian studies centred on renewable consumption [3] and the financial determinants of renewable uptake [4], the present model isolates the long-run environmental association of the investment channel itself.

The magnitude should be interpreted using the exact measurement units in the archived dataset. The earlier draft's statement that a one-billion-unit increase in REI reduces emissions by a specified number of million metric tons should only be retained if the REI unit is verified as billions of the stated currency and CAEM is verified in million metric tons.

The revised discussion therefore prioritizes sign, statistical significance and relative comparison until the metadata are fully documented.

RAI has a negative but statistically insignificant coefficient ($\beta = -8.58\times10^{-6}$, p = 0.2068). This differs from the strong REI result and is one of the study's most important comparative findings. Agriculture and forestry investment can generate mitigation through efficient irrigation, renewable-powered processing, agroforestry and reduced land degradation, but aggregate effects may be delayed or offset by deforestation, fertilizer use, livestock emissions and expansion of cultivated land. [7] similarly show that agriculture-related drivers have heterogeneous effects across the emissions distribution.

The insignificant national aggregate coefficient, therefore, points to the need for more granular project and technology data rather than abandonment of climate-smart agriculture.

GDP is positive and statistically significant ($\beta = 7.50\times10^{-11}$, p = 0.0149). This result indicates that economic expansion over the study period remained associated with higher emissions after accounting for renewable investment. It is consistent with Nigerian evidence that non-renewable energy use and growth remain linked to carbon emissions [10].

The finding implies that renewable investment alone is insufficient if industrial production, transport, captive generation and extractive activity continue to expand through carbon-intensive technologies.

The model explains approximately 90% of the variation in CAEM, with an adjusted R^2 of 0.884. Because trending macroeconomic series can generate high explanatory power, the R^2 is interpreted alongside the unit-root and cointegration evidence rather than as stand-alone proof of model quality. The small sample and high correlations among some regressors also warrant caution.

4.5. Granger-Causality Results

None of the pairwise null hypotheses is rejected at the 5% level. The result does not contradict the significant FMOLS coefficient. FMOLS estimates a long-run equilibrium association, whereas the Granger test asks whether lagged values improve short-run prediction conditional on the chosen lag structure. Long project-development periods, implementation lags, irregular investment timing and a sample of only 24 annual observations can allow a long-run relationship to coexist with weak short-run predictive power.

This distinction also clarifies the comparison with studies that report causal relationships using different variables, periods or methods. A consumption series can respond more quickly to output and emissions than an investment series that must pass through procurement, construction, grid connection and utilization. Consequently, divergence from consumption-based causality findings should be interpreted as evidence that variable definition and transmission lag matter.

Table 8. Pairwise Granger-causality results. Source: Authors' computation

Null hypothesis	F-statistic	p-value	Decision at 5%
REI does not Granger-cause CAEM	0.97389	0.3977	Do not reject
CAEM does not Granger-cause REI	0.80582	0.4631	Do not reject
RAI does not Granger-cause CAEM	0.03938	0.9615	Do not reject
CAEM does not Granger-cause RAI	1.11844	0.3497	Do not reject
GDP does not Granger-cause CAEM	2.35555	0.1250	Do not reject
CAEM does not Granger-cause GDP	2.26884	0.1339	Do not reject

4.6. Comparative Performance and Why the Results Differ

The study's strongest comparative result is the separation of REI from RAI. Aggregating both into one renewable-investment indicator would conceal the fact that the energy channel is statistically strong while the agriculture/forestry channel is not. This disaggregation improves policy diagnosis: energy investment appears to have a measurable long-run emissions association, while agriculture-related investment requires better targeting, scale and measurement before a comparable national effect can be established.

The FMOLS approach also improves comparability for this specific dataset because all variables are I(1) and cointegrated. Relative to a regression in levels that ignores non-stationarity, FMOLS is designed to correct asymptotic bias from endogeneity and serial correlation in cointegrating relationships [13]. Relative to studies using ARDL or GMM, however, the present estimator should not be described as universally superior. Estimator performance depends on integration order, sample structure, cross-sectional dimension, lag dynamics and research objective. The defensible claim is that FMOLS is well aligned with the observed time-series properties and the long-run research question.

The better explanatory clarity of the present findings arises from four design choices: direct use of investment proxies, disaggregation of investment categories, explicit control for GDP, and separation of long-run association from short-run predictive causality.

These choices help explain why the REI result aligns with investment-based international evidence [5, 6] while the RAI result is weaker and more consistent with heterogeneous agriculture–emissions evidence [7].

5. Policy Implications and Actionable Recommendations

First, renewable-energy finance should be scaled through instruments that reduce project risk rather than through undifferentiated expenditure expansion. Concessional co-financing, partial risk guarantees, local-currency facilities, transparent procurement and predictable mini-grid regulation can improve the probability that committed capital becomes operational capacity. Programmes such as DARES provide a useful platform for linking finance to measurable access, generation and generator-displacement indicators [2].

Second, renewable agriculture and forestry investment should be redesigned around measurable mitigation pathways. Funding should distinguish solar irrigation, renewable-powered cold chains, agroforestry, land restoration, efficient fertilizer management and biomass valorization rather than combining them into a broad aggregate category. Each project should specify baseline emissions, expected reductions, adoption rates and maintenance arrangements. This would improve both environmental effectiveness and future empirical measurement.

Third, economic policy should aim to decouple GDP growth from emissions. Industrial energy-efficiency standards, cleaner captive power, public transport investment, methane control, reduced gas flaring and renewable electricity for productive use should complement renewable generation. The positive GDP coefficient indicates that growth policy and climate policy cannot be designed independently.

Fourth, benefit-sharing should be explicit. Publicly supported projects should disclose affordability criteria, community engagement processes, local employment and procurement targets, grievance mechanisms and inclusion indicators. Rural households, women-led enterprises, smallholder farmers and low-income urban communities should not bear transition costs without proportionate access to benefits.

Fifth, monitoring should shift from financial commitments alone to an investment-to-impact chain in a manner that the amount committed would lead to the amount disbursed and then to capacity installed and to capacity operational. This should also lead to fossil generation displaced and then to emissions avoided before it finally leads to households and firms served. This framework would make policy evaluation more transparent and would generate higher-quality data for future causal research.

6. Limitations, Implications and Future Research

The study has several limitations. The sample contains only 24 annual observations, limiting statistical power and the complexity of dynamic models that can be estimated reliably. National aggregates may hide regional differences in renewable resources, grid conditions, land use and project implementation. The investment series may also combine commitments and realized expenditure or may be affected by currency conversion and inflation unless carefully standardized. Carbon emissions capture only the environmental dimension of sustainable development and do not measure access, affordability, employment, health or distributional outcomes.

The FMOLS estimates establish a long-run association under cointegration assumptions but do not by themselves identify a structural causal effect. Granger non-causality is sensitive to lag length and sample size and should not be interpreted as proof that investment has no causal mechanism. Structural breaks associated with major policy changes, oil-price shocks, recessions, the COVID-19 period and energy-market reforms may also affect parameter stability.

Future research should use project-level or state-level panel data, distinguish committed from disbursed investment, separate technologies, and test implementation lags. Distributional analysis should examine who receives electricity access, jobs, procurement opportunities and agricultural productivity gains.

Methodologically, future studies can compare FMOLS with dynamic OLS, ARDL bounds models, nonlinear ARDL, structural-break cointegration and, where panel data become available, second-generation panel estimators. Mixed-method case studies of successful and stalled projects would also help explain the governance and stakeholder mechanisms behind quantitative coefficients.

7. Conclusion

This study examined the long-run relationship between renewable investment and carbon emissions in Nigeria from 2000 to 2023. The results show that renewable energy investment is negatively and significantly associated with carbon emissions, renewable agriculture and forestry investment has a negative but statistically insignificant coefficient, and GDP is positively and significantly associated with emissions. No pairwise Granger-causal relationship with carbon emissions is detected at the 5% level. The findings demonstrate that renewable investment categories should not be treated as homogeneous. Energy investment shows a measurable long-run environmental association, whereas the agriculture and forestry channel requires better scale, targeting, implementation and measurement.

At the same time, the positive GDP coefficient shows that renewable finance must be accompanied by cleaner production and broader structural decarbonization. The study's contribution lies in its disaggregated investment perspective and in distinguishing long-run association from short-run predictive causality. Policy should therefore combine sustained renewable-energy finance with rigorous project implementation, technology-specific climate-smart agriculture, cleaner industrial growth, transparent monitoring and equitable benefit-sharing. The transition will be more credible when investment success is measured not only by capital committed but by operational capacity, fossil energy displaced, emissions avoided and development benefits distributed across communities.

Declarations

Ethics Approval

This is not applicable in this study because the study uses aggregate, publicly available secondary data and does not involve human participants, personal data or animal subjects.

Conflict of Interest

The authors declare "no conflict of interest."

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Data Availability

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