

Energy Production and Environmental Quality in Nigeria

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Abstract

This study investigated the impact of energy production on environmental quality in Nigeria, proxied by carbon dioxide emission, over the period 1990 to 2025. Energy production was proxied by total energy production, renewable energy consumption, electricity generation, fossil fuel energy production, and urbanization. The study made use of annual time series data sourced mainly from the World Bank World Development Indicators (WDI) and the International Energy Agency (IEA). The Augmented Dickey-Fuller (ADF) unit root test, the ARDL bounds cointegration test, and the Autoregressive Distributed Lag (ARDL) model were employed as the data analysis techniques. The findings revealed that energy production is cointegrated with environmental quality in the long run, with a bounds test F-statistic of 7.513330 exceeding the upper bound at all conventional significance levels. Total energy production had a negative and statistically insignificant effect on carbon dioxide emission in the long run. Renewable energy consumption had a negative and statistically significant effect on carbon dioxide emission in the long run. Electricity generation had a negative and statistically insignificant effect on carbon dioxide emission in the long run. Fossil fuel energy production had a negative and statistically significant effect on carbon dioxide emission in the long run. Urbanization had a negative and statistically significant effect on carbon dioxide emission in the long run. The study concluded that energy production has a substantial impact on environmental quality in Nigeria. The study recommended, among other measures, that the Federal Government of Nigeria, through the Federal Ministry of Power and the Energy Commission of Nigeria, should intensify investment in renewable energy infrastructure such as solar, wind, and hydroelectric power projects.

1.0 Introduction

The energy sector continues to be the foundation of contemporary economic systems, while environmental issues continue to redefine the trajectory of sustainable development. Environmental quality can be defined as the overall condition of the natural environment, measured by physical, chemical, and biological indicators that determine its capacity to sustain human life and ecological systems without adverse effect (United Nations Environment Programme, 2023; World Health Organization, 2022). The International Energy Agency (2023) reports Nigeria's greenhouse gas emissions to be approximately 334 million metric tonnes of CO₂ equivalent in 2021, about 0.71 percent of global greenhouse gas emissions, with the energy sector accounting for approximately 62 percent of the country's total emissions, underscoring the close relationship between the energy sector and its environmental consequences. Energy production is the act of obtaining usable energy from natural resources for use in industrial, commercial, and domestic applications, encompassing the extraction, transformation, and

distribution of energy carriers that sustain economic activity. For the purpose of this study, energy production is viewed as a multi-dimensional concept spanning total energy production, fossil fuel energy production, renewable energy consumption, electricity generation, and the urbanization that these energy systems both serve and are shaped by. Nigeria's energy mix relies overwhelmingly on hydrocarbon sources, comprising about 98.6 percent of the country's energy supply as of 2021 (International Energy Agency, 2023), a dominance that intensifies environmental pressures through higher greenhouse gas emissions and associated environmental damage.

Statement of the Problem

The rapid rate at which Nigeria is industrializing and urbanizing, alongside its continued reliance on fossil-fuel-powered energy production, has increasingly jeopardized environmental quality. In 2021, Nigeria emitted an estimated 334 million metric tonnes of carbon dioxide equivalent greenhouse gases, with the energy industry contributing about 62 percent of these emissions (International Energy Agency, 2023). Though Nigeria has made efforts to diversify its energy sources, fossil fuels still dominate its energy supply, and the country flares more than 7 billion cubic metres of gas annually, making it one of the world's largest gas-flaring nations (Reuters, 2025). Renewable energy potential, including solar, wind, and hydropower, remains underutilised, with renewables accounting for less than 20 percent of total primary energy supply in recent years, even as most existing studies consider only one dimension of energy production or a short-term impact on the energy system, leaving the dynamic, multi-dimensional relationship between energy production and environmental quality comparatively understudied. It is against this backdrop that this study empirically examines the effect of energy production on environmental quality in Nigeria from 1990 to 2025, specifically ascertaining the effect of total energy production, renewable energy consumption, electricity generation, fossil fuel energy production, and urbanization on carbon dioxide emission.

2.0 Literature Review

Theoretical Framework

This study is anchored on two complementary theories: The Environmental Kuznets Curve Theory, which explains the relationship between the scale of energy-driven economic activity and environmental degradation in Nigeria, and Ecological Modernization Theory, which explains how technological and institutional change can decouple energy production from environmental harm.

a. Environmental Kuznets Curve Theory

The Environmental Kuznets Curve Theory, formulated by Kuznets (1955) and empirically extended to the environmental domain by Grossman and Krueger (1991, 1995), holds that income per capita and environmental degradation follow an inverted U-shaped relationship: pollution and natural resource degradation rise with economic development in the early stages, driven by industrialisation, urbanisation, and reliance on fossil-fuel-based energy production, but beyond a turning point, further income growth is accompanied by improving environmental quality as cleaner technologies are adopted, environmental regulation tightens, and the economy shifts from more polluting to less polluting sectors. The theory attributes environmental impact to a scale effect, arising from the sheer size of economic activity, a composition effect, arising from structural change in the economy, and a technique effect, arising from technological

innovation and improved production methods. Applied to this study, the Environmental Kuznets Curve Theory provides the basis for expecting that Nigeria, with an economy still heavily reliant on fossil fuel extraction and energy production, particularly crude oil and natural gas, remains on the ascending segment of the curve, where energy-driven economic activity continues to exacerbate carbon dioxide emission, while offering a framework within which structural transformation, renewable energy adoption, and stronger regulatory enforcement could, over time, move the country toward the downward-sloping segment associated with improving environmental quality.

b. Ecological Modernization Theory

Ecological Modernization Theory, propounded by Huber and further developed by Mol in the early 1990s, holds that environmental protection and economic development can coexist and mutually reinforce one another, and that the adoption of new technology, institutional reform, and sustainable production practices can minimise environmental degradation without sacrificing economic growth. The theory posits that environmental issues are not an inescapable by-product of industrialisation, and that cleaner technologies, regulatory reform, and market-based instruments can meaningfully alleviate them, with environmental quality improved through processes of industrial restructuring, energy transition, and green technology adoption. Applied to this study, Ecological Modernization Theory provides the basis for expecting that Nigeria's continuing dependence on fossil fuels and the associated carbon dioxide emission, gas flaring, and oil spills are not permanent features of the country's development path, but can be meaningfully reduced through technological innovation, the expansion of renewable energy consumption and cleaner electricity generation, and stronger institutional and regulatory frameworks that allow energy production to continue supporting economic growth while progressively decoupling that growth from environmental harm. Taken together, the Environmental Kuznets Curve Theory and Ecological Modernization Theory suggest that Nigeria's environmental quality is shaped both by the scale and structure of its current, largely fossil-fuel-dependent energy production, and by the extent to which technological and institutional modernisation can decouple continued energy production from further environmental degradation, a joint theoretical grounding that underlies the empirical model adopted in this study.

Empirical Review

Almulhim, Inuwa, Chaouachi, and Samour (2025) tested the impact of renewable energy and institutional quality on consumption-based carbon dioxide emissions from 1996 to 2020, using the Method of Moments Quantile Regression, Fixed Effects Ordinary Least Squares, and Generalised Method of Moments techniques. The study found that renewable energy consumption and enhanced institutional quality negatively and significantly affected carbon dioxide emissions across most quantiles, while economic growth positively and significantly affected emissions, and recommended that renewable energy expansion be complemented by institutional reform to improve environmental quality in emerging economies.

Kinuthia, Kemboi, Onyango, and Adaramola (2025) examined renewable energy consumption and carbon emissions in Sub-Saharan Africa, and the moderating role of institutional quality, using panel data from 24 Sub-Saharan African countries between 2000 and 2023 and panel fixed-effects estimation. The study found that renewable energy consumption was itself a significant factor in reducing carbon emissions, and that higher institutional quality strengthened

this mitigating effect, recommending that governance reform accompany renewable energy policy to secure sustainable environmental outcomes.

Suri, de Chalendar, and Azevedo (2025) assessed the real implications for carbon dioxide emissions as renewable electricity generation increases in the United States electricity sector, using plant-level production data. The study found that increased renewable generation substantially decreased carbon dioxide emissions but introduced integration challenges that altered the operational characteristics of fossil fuel plants, concluding that grid flexibility mechanisms are needed to maximise the emission-reduction benefits of renewable generation.

Alajmi (2024) investigated energy consumption and carbon emissions in Saudi Arabia using national time series data from 1990 to 2022, the Augmented Dickey-Fuller unit root test, Johansen cointegration test, and the Autoregressive Distributed Lag model. The study found that fossil fuel energy consumption positively and significantly contributed to carbon dioxide emissions, while technological innovation successfully mitigated the environmental damage from fossil fuel energy use, recommending energy diversification and technological development for oil-dependent economies. Gyamfi, Bekun, and Adebayo (2025) examined renewable energy consumption and environmental quality in the BRICS-T countries from 1992 to 2023, using the Augmented Mean Group estimator and Dumitrescu-Hurlin panel causality test. The study found that renewable energy consumption significantly mitigated carbon emissions and ecological footprint in the long run, while fossil fuel use and rapid urbanisation exacerbated environmental degradation, concluding that renewable energy transition is essential for maintaining environmental quality in high-growth emerging countries.

Silva, Pereira, and Costa (2025) researched renewable energy use and environmental performance in ten Latin American countries from 1995 to 2022, using panel quantile regression. The study found that renewable energy use had a statistically significant negative impact on emissions intensity, particularly in high-emission economies, concluding that renewable energy implementation represents a viable pathway to reducing the region's socioeconomic-ecological pressures. Balcilar, Bekun, and Usman (2025) examined renewable energy consumption and environmental quality using nonlinear evidence from G20 economies spanning 1990 to 2022, employing a nonlinear panel threshold regression model and system Generalised Method of Moments. The study found that renewable energy consumption reduced emissions beyond certain development thresholds, while energy intensity increased emissions and foreign direct investment inflows had a positive effect on emissions, concluding that renewable energy policy delivers stronger environmental benefits in structurally advanced economies.

Mensah, Adams, and Boateng (2024) examined renewable energy consumption and carbon emissions in African economies, and the role of governance and technological innovation, using a balanced panel of 30 African countries from 1998 to 2021 and Dynamic Ordinary Least Squares. The study found that renewable energy consumption significantly reduced carbon dioxide emissions, with the effect more pronounced in countries with stronger governance and technological progress, concluding that institutional strengthening and innovation complement renewable adoption in boosting environmental sustainability in Africa.

Rahman and Alam (2024) conducted a panel data analysis of renewable energy consumption and environmental sustainability in South Asia, covering Bangladesh, India, Pakistan, Sri Lanka, and Nepal from 2000 to 2022, using a panel Vector Error Correction Model and Granger causality test. The study found a significant long-run equilibrium relationship between renewable energy consumption and environmental indicators, with renewable energy use significantly decreasing carbon dioxide emissions and air pollution, concluding that accelerated deployment of

renewables is necessary to improve environmental conditions in the region.

Adebayo and Kirikkaleli (2025) explored electricity generation and environmental quality in emerging markets from a nonlinear perspective, using panel data from 20 emerging economies between 1992 and 2022 and nonlinear panel threshold regression with system Generalised Method of Moments. The study found that a rise in fossil-based electricity generation significantly worsened environmental quality, particularly beyond certain industrialisation thresholds, while renewable-based generation had a positive mitigating effect, concluding that the environmental effect of electricity generation depends on the underlying energy structure and level of industrial development. Dogah, Mensah, and Bekun (2025) studied hydroelectric power generation and environmental sustainability across 12 West African countries from 1995 to 2021, using panel quantile regression and Dynamic Ordinary Least Squares. The study found a significant carbon-emission-reducing effect of hydroelectric generation, particularly in high-emission economies, concluding that hydroelectric development has a positive environmental effect in West Africa.

Shahbaz, Raghutla, and Chittedi (2025) examined electricity production and environmental degradation in the BRICS economies using data from 1990 to 2023 and Panel ARDL alongside Fully Modified Ordinary Least Squares techniques. The study found that coal-based electricity generation significantly contributed to environmental degradation, while renewable-based electricity generation significantly reduced it, concluding that decarbonisation reforms in the electricity sector are crucial for environmental sustainability in the BRICS economies.

Acheampong and Boateng (2024) examined the electricity generation mix and environmental quality in Sub-Saharan Africa using panel data from 28 countries between 1995 and 2022, Pedroni cointegration analysis, and the Augmented Mean Group estimator. The study found that fossil-fuel-based electricity generation significantly contributed to carbon dioxide emissions, while renewable electricity generation contributed negatively to emissions in the long run, concluding that restructuring the electricity generation mix toward a higher share of renewables is needed to improve environmental quality in the region.

Balsalobre-Lorente, Driha, and Bekun (2024) studied electricity generation, economic complexity, and environmental sustainability in OECD countries from 1994 to 2021, using Westerlund cointegration analysis and the Common Correlated Effects Mean Group estimator. The study found that thermal electricity generation had a significant positive impact on emissions intensity while renewable electricity generation capacity had a positive environmental effect, concluding that more sophisticated, developed economies derive greater environmental benefit from renewable electricity generation.

Ozturk and Ullah (2024) examined coal-fired electricity generation and environmental degradation in India, Pakistan, Bangladesh, and Sri Lanka using country-level time series data from 1990 to 2022, ARDL bounds testing, and a Vector Error Correction Model. The study found a positive long-run relationship between coal-fired electricity generation and environmental pollution and degradation indicators, concluding that a gradual shift away from coal is crucial for improved environmental quality in South Asia.

Lin and Raza (2024) conducted a panel analysis of the sources of carbon emissions across China's provinces from 2005 to 2020, using panel fixed effects and spatial econometric models. The study found that provinces with a higher share of coal-based power generation had significantly higher carbon emissions, while provinces with higher renewable shares had lower emissions, concluding that optimising the structure of electricity generation is essential for environmental sustainability in industrialising regions.

Destek and Sinha (2025) analysed trends in urbanization, energy use, and environmental sustainability in OECD countries from 1990 to 2023, using panel Autoregressive Distributed Lag and Fully Modified Ordinary Least Squares methods. The study found that urbanisation had a significant positive impact on ecological footprint in the long run, while renewable energy consumption had a significant negative impact, concluding that clean energy transition and innovation-driven development can limit the environmental cost of urbanisation even in advanced economies. Wang, Zhang, and Li (2024) studied urbanization and environmental quality using a dynamic panel of 22 Asian economies from 1995 to 2022, employing second-generation panel unit root tests, Westerlund cointegration analysis, and system Generalised Method of Moments estimation. The study found that urbanisation significantly raised carbon dioxide emissions in the short run, with a reduced effect in the long run, consistent with the Environmental Kuznets Curve hypothesis, concluding that sustainable urban development and green energy infrastructure are key to alleviating environmental stress from rising urbanisation in Asia. Bekun, Alola, and Gyamfi (2024) examined urbanization and environmental degradation in Sub-Saharan Africa, and the role of institutional quality, using panel data from 30 countries between 1996 and 2021, the Augmented Mean Group estimator, and Dumitrescu-Hurlin panel causality tests. The study found that urbanisation contributed to higher carbon dioxide emission levels regardless of institutional strength, with the urban-rural gap widening over time, concluding that improved governance structures are needed to offset the environmental effects of rapid urbanisation in developing regions. Pata and Isik (2024) examined urbanization and environmental quality in the European Union using panel data for member states from 1995 to 2022 and panel quantile regression. The study found that urbanisation had a positive impact on greenhouse gas emissions in less affluent European Union countries, but a smaller effect in more affluent countries with greater renewable energy integration, concluding that urban sustainability approaches combined with renewable energy adoption reduce the environmental impact of urbanisation.

Evaluation of Empirical Literature

The reviewed studies reveal that the relationship between energy production and environmental quality has been extensively examined across diverse regional contexts, including Sub-Saharan Africa, Latin America, Asia, the OECD, and the BRICS economies, predominantly using panel data techniques such as the Method of Moments Quantile Regression, system Generalised Method of Moments, and panel Autoregressive Distributed Lag approaches. However, comparatively few studies have jointly examined total energy production, renewable energy consumption, electricity generation, fossil fuel energy production, and urbanization within a single country-specific time series framework for Nigeria extending to 2025. This study addresses this gap by jointly modelling all five dimensions of energy production against carbon dioxide emission within a single ARDL framework specific to Nigeria.

3.0 Methodology

This study used an ex-post facto research design, which is considered ideal for empirical investigations involving secondary data. It has been described as appropriate for investigating the cause-and-effect relationship between dependent and independent variables based on the fact that the datasets involved cannot be manipulated by the researcher. Also, the study utilized annual time series data. Specifically, the data focused on the impact of energy balance (energy consumption, electricity consumption, fossil fuel consumption and energy use) and Carbon

Dioxide Emission as a proxy for Environmental quality. The datasets were obtained from the World Banks World Development Indicator (WDI).

Model Specification

This section develops and specifies the model adopted in this study to empirically determine the effect of energy production on environmental quality in Nigeria. Theoretically, the model of this study is based on the Environmental Kuznets Curve Theory and Ecological Modernization Theory. Since this study is interested in establishing relationships between variables, a multiple linear model is adopted.

The functional form of the model is specified as:

$$CO2e = f(TEP, REC, ELG, FFEP, URZ) \quad (1)$$

Expressed in its mathematical form:

$$CO2e_t = \pi_0 + \pi_1 TEP_t + \pi_2 REC_t + \pi_3 ELG_t + \pi_4 FFEP_t + \pi_5 URZ_t \quad (2)$$

Expressed in its econometric form:

$$CO2e_t = \pi_0 + \pi_1 TEP_t + \pi_2 REC_t + \pi_3 ELG_t + \pi_4 FFEP_t + \pi_5 URZ_t + U_t \quad (3)$$

A Priori Expectation: $\pi_1 > 0$; $\pi_2 < 0$; $\pi_3 > 0$; $\pi_4 > 0$; $\pi_5 > 0$.

Where: CO2e = Carbon Dioxide Emission, TEP = Total Energy Production, REC = Renewable Energy Consumption, ELG = Electricity Generation, FFEP = Fossil Fuel Energy Production, URZ = Urbanization, π_0 = Constant, π_1 – π_5 = Parameters, U_t = Error term.

Description and Operational Measures of Variables

Dependent Variable

Carbon Dioxide Emission (CO2e): the release of carbon dioxide into the atmosphere, primarily through the combustion of fossil fuels, industrial processes, and land-use change, measured in metric tons per capita, serving as the proxy for environmental quality in this study.

Independent Variable

Total Energy Production (TEP): the aggregate quantity of energy generated within Nigeria from all sources, measured in kilotonnes of oil equivalent.

Renewable Energy Consumption (REC): the share of final energy consumption derived from renewable sources such as hydro, solar, wind, and biomass, measured as a percentage of total final energy consumption.

Electricity Generation (ELG): the total volume of electricity generated within Nigeria, measured in billion kilowatt-hours.

Fossil Fuel Energy Production (FFEP): the share of total energy production accounted for by fossil fuels, including crude oil, natural gas, and coal, measured as a percentage.

Urbanization (URZ): the proportion of Nigeria's total population residing in urban areas, measured as a percentage.

Data Analysis Technique

The analytical procedure for this study began with descriptive statistics for each series, followed by the Augmented Dickey-Fuller (ADF) unit root test and the ARDL bounds cointegration test, to ensure the estimated model is not spurious and that a cointegrating regression can be estimated. In estimating the model, the study adopted the Autoregressive Distributed Lag (ARDL) technique, since the unit root test results showed evidence of mixed stationarity, with a mixture of I(0) and I(1) series. Post-estimation diagnostic tests, including the Jarque-Bera

normality test, the Breusch-Godfrey serial correlation test, the Breusch-Pagan-Godfrey heteroskedasticity test, the Ramsey RESET test, and the CUSUM stability test, were also conducted. Data analysis was facilitated by EViews statistical package.

4.0 Results and Discussion

Descriptive Statistical Analysis

Table 1: Descriptive Statistics

	CO2E	TEP	REC	ELG	FFEP	URZ
Mean	0.6833	230,605.9	105.9806	27.8556	33.1694	49.5000
Median	0.6000	232,442.7	84.3000	25.8000	43.5000	49.5000
Maximum	0.9000	297,504.1	881.0000	41.9000	53.4000	63.0000
Minimum	0.5000	150,452.4	79.9000	13.0000	0.0000	35.0000
Std. Dev.	0.1082	44,666.52	132.8875	8.4919	21.2451	8.6272
Skewness	0.6095	-0.2905	5.7433	0.0188	-0.8758	-0.0260
Kurtosis	2.1612	1.7706	34.0010	3.0746	2.9249	1.7665
Jarque-Bera	3.2840	2.7733	1639.511	2.6370	6.3361	2.2863
Probability	0.1936	0.2499	0.0000	0.2675	0.0421	0.3188
Observations	36	36	36	36	36	36

Source: Authors' Computation, 2026.

Carbon dioxide emission averaged 0.6833 metric tons per capita over the 1990–2025 period, ranging from 0.50 to 0.90 metric tons per capita, with a relatively low standard deviation of 0.1082, indicating moderate variation over the study period, and a Jarque-Bera probability of 0.1936 confirming a normal distribution. Total energy production averaged 230,605.9 kilotonnes of oil equivalent, with a standard deviation of 44,666.52 reflecting substantial fluctuation, potentially due to shifts in energy demand, industrial production, and energy-sector reforms. Renewable energy consumption averaged 105.9806 percent of total final energy consumption, with an extremely high standard deviation (132.8875) and kurtosis (34.0010), and a Jarque-Bera probability of 0.0000, rejecting normality and reflecting a small number of extreme observations, attributable to inconsistent investment in renewable energy infrastructure and fluctuating sector policy. Electricity generation averaged 27.8556 billion kilowatt-hours, with a comparatively moderate standard deviation (8.4919) and a near-normal, mesokurtic distribution (kurtosis of 3.0746). Fossil fuel energy production averaged 33.1694 percent of total energy production, with a standard deviation of 21.2451 indicating substantial volatility, linked to crude oil production levels, international oil prices, and disruptions in the petroleum sector, and a Jarque-Bera probability of 0.0421 rejecting normality. Urbanization averaged 49.5000 percent, with a comparatively low standard deviation (8.6272) suggesting a relatively stable, progressive rate of urban population growth over the study period.

Unit Root Test

Table 2: Augmented Dickey-Fuller (ADF) Test Results

Variables	ADF (Level)	5% Critical (Level)	ADF (1st Diff.)	5% Critical (1st Diff.)	Order of Integration
LCo2e	-1.533988	-2.951125	-7.783576	-2.951125	I(1)
LTEP	-1.616947	-2.948404	-6.289923	-2.951125	I(1)
REC	-5.881707	-2.948404			I(0)
ELG	-0.920294	-2.948404	-6.794933	-2.951125	I(1)

Variables	ADF (Level)	5% Critical (Level)	ADF (1st Diff.)	5% Critical (1st Diff.)	Order of Integration
FFEP	-0.530992	-2.948404	-6.162406	-2.951125	I(1)
URZ	-1.197269	-2.960411	-6.285394	-2.960411	I(1)

Source: Authors' Computation, 2026.

Renewable energy consumption is stationary at level, I(0), while carbon dioxide emission, total energy production, electricity generation, fossil fuel energy production, and urbanization are non-stationary at level but become stationary after first differencing, I(1). This mixed order of integration, with no variable integrated beyond first difference, justifies the application of the ARDL bounds testing approach.

ARDL Bounds Cointegration Test

Table 3: ARDL Bounds Cointegration Test Results

Test Statistics	Value	K
F-statistics	7.513330	5
Significance	I (0)	1(1)
10%	2.75	3.99
5%	3.35	4.77
2.5%	3.25	4.49
1%	4.76	6.67

Source: Authors' Computation, 2026.

The computed F-statistic of 7.513330 exceeds the upper bound critical value of 4.77 at the 5 percent significance level, and even the 1 percent upper bound of 6.67, providing strong evidence to reject the null hypothesis of no cointegration and confirming a long-run relationship between carbon dioxide emission, total energy production, renewable energy consumption, electricity generation, fossil fuel energy production, and urbanization.

Short Run ARDL Model Estimation

Table 4: ARDL Short-Run Estimation Results

Variable	Coefficient	Std. Error	t-Statistics	Prob
C	0.698553	0.147701	4.729511	0.0002
D(LTEP)	0.558442	0.116277	4.802689	0.0002
D(LTEP(-1)	0.617708	0.389838	1.584526	0.1326
D(LTEP(-2)	0.362702	0.336354	1.078334	0.2969
D(REC)	-0.000264	7.08E-05	-3.725438	0.0018
D(REC(-1)	0.000217	0.000110	1.963307	0.0672
D(REC(-2)	9.15E-05	7.26E-05	1.260394	0.2256
D(ELG)	0.006519	0.005550	1.174643	0.2573
D(ELG(-1)	0.014280	0.006176	2.312162	0.0344
D(ELG(-2)	-0.005938	0.003577	-1.660187	0.1163
D(FFEP)	0.000883	0.001394	0.633457	0.5354
D(FFEP(-1)	0.002694	0.001958	1.375649	0.1879
D(FFEP(-2)	0.004503	0.001935	2.327021	0.0334
D(URZ)	0.076370	0.030961	2.466672	0.0253
D(URZ(-1)	0.010453	0.040577	0.257608	0.8000
D(URZ(-2)	0.033522	0.030618	1.094850	0.2898

Ecm (-1)*	-0.558072	0.119159	-4.683430	0.0002
Adj R ² = 0.722058, F-statistics = 6.195751 (0.000358), DW = 1.944611				

Source: Authors' Computation, 2026.

Interpretation of the Parameters

In the short run, total energy production has a positive and significant contemporaneous effect on carbon dioxide emission (coefficient 0.558442, $p = 0.0002$), while its lagged terms are positive but statistically insignificant. Renewable energy consumption has a negative and significant contemporaneous effect (coefficient -0.000264, $p = 0.0018$), with its first lag significant only at the 10 percent level. Electricity generation has a positive but statistically insignificant contemporaneous effect, though its first lag is positive and significant (coefficient 0.014280, $p = 0.0344$). Fossil fuel energy production has a positive but statistically insignificant contemporaneous effect, though its second lag is positive and significant (coefficient 0.004503, $p = 0.0334$). Urbanization has a positive and significant contemporaneous effect on carbon dioxide emission (coefficient 0.076370, $p = 0.0253$), with its lagged terms statistically insignificant.

Interpretation of Adjusted R-Squared

The Adjusted R-squared value of 0.722058 from the short-run estimates of the ARDL model in Table 4 indicates that the estimated model is well fitted, as systematic changes in the explanatory variables, total energy production, renewable energy consumption, electricity generation, fossil fuel energy production, and urbanization, explain approximately 72 percent of the variation in carbon dioxide emission, while the remaining 28 percent is captured by the error term, representing factors outside the model.

Interpretation of CointEq (-1) Values

The error correction term, ECM (-1), is negative and highly significant at -0.558072 ($p = 0.0002$), confirming that the model converges toward long-run equilibrium following a shock. The coefficient indicates that approximately 55.81 percent of any short-run deviation from long-run equilibrium is corrected within one year, a relatively fast speed of adjustment, implying that deviations in carbon dioxide emission arising from shocks to Nigeria's energy production structure are substantially, though not immediately, corrected within a single year.

Long Run ARDL Model Estimation

Table 5: ARDL Long-Run Estimation Results

Variable	Coefficient	Std. Error	t-Statistics	Prob
LTEP	-0.066293	0.812046	-0.081637	0.9355
REC	-0.000760	0.000223	-3.408042	0.0020
ELG	-0.004605	0.004172	-1.103869	0.2790
FFEP	-0.011123	0.004216	-2.638470	0.0084
URZ	-0.071626	0.025914	-2.784026	0.0096

Source: Authors' Computation, 2026.

Interpretation of the Parameters

In the long run, total energy production has a negative but statistically insignificant effect on carbon dioxide emission (coefficient -0.066293, $p = 0.9355$). This negative relationship does not conform to a priori expectation, which anticipated that higher aggregate energy production

would raise industrial activity and energy use and thereby increase emissions; however, since the relationship is statistically insignificant, the study cannot conclude that total energy production meaningfully influences carbon dioxide emission in Nigeria over the long run. Renewable energy consumption has a negative and statistically significant effect (coefficient -0.000760, $p = 0.0020$), consistent with a priori expectation that expanding renewable energy reduces reliance on fossil fuels and thereby lowers carbon dioxide emission. Electricity generation has a negative but statistically insignificant effect (coefficient -0.004605, $p = 0.2790$); given Nigeria's continued reliance on fossil-fuel-based generation, this negative sign does not conform to a priori expectation, but its lack of significance means no reliable long-run relationship can be established. Fossil fuel energy production has a negative and statistically significant effect (coefficient -0.011123, $p = 0.0084$); although a negative sign for fossil fuel production is unexpected on a priori grounds, given fossil fuels' established role in emissions, the significant negative coefficient may reflect improvements in extraction and processing efficiency, or a growing share of associated gas capture and flare-reduction initiatives, over the more recent years of the sample. Urbanization has a negative and statistically significant effect (coefficient -0.071626, $p = 0.0096$); while urbanization is conventionally expected to raise emissions through increased transportation, housing, and industrial demand, the significant negative coefficient observed here may reflect the environmental efficiency gains associated with denser, more organised urban infrastructure relative to the dispersed, less regulated energy use patterns of rural and peri-urban areas in Nigeria.

Diagnostic Tests

Table 6: Post-Estimation Test Results

Test	F-statistic	Prob.	Decision
Ramsey RESET	3.287383	0.0999	Retain H_0 (correctly specified)
Breusch-Godfrey Serial Correlation LM	0.070476	0.9325	Retain H_0 (no serial correlation)
Breusch-Pagan-Godfrey Heteroskedasticity	0.383282	0.9717	Retain H_0 (homoscedastic)
Jarque-Bera Normality	2.80904	0.245484	Retain H_0 (normal residuals)

Source: *Author's Computation, 2026.*

The Ramsey RESET test ($p = 0.0999$) confirms that the model is correctly specified, with no evidence of functional form misspecification. The Breusch-Godfrey serial correlation LM test ($p = 0.9325$) confirms the absence of serial correlation in the model residuals. The Breusch-Pagan-Godfrey heteroskedasticity test ($p = 0.9717$) confirms that the residuals are homoscedastic, with constant variance. The Jarque-Bera normality test ($p = 0.245484$) confirms that the residuals are normally distributed. The CUSUM stability test further confirms that the estimated coefficients remain within the 5 percent significance boundaries throughout the sample period, indicating stability of the model.

Discussion of Findings

The findings show that renewable energy consumption, fossil fuel energy production, and urbanization all exert a negative and statistically significant effect on carbon dioxide emission in Nigeria in the long run, while total energy production and electricity generation exert a negative but statistically insignificant effect. The significant negative effect of renewable energy consumption is consistent with Gyamfi, Bekun and Adebayo (2025), Mensah, Adams and

Boateng (2024), and Rahman and Alam (2024), all of whom found that renewable energy consumption significantly reduces carbon emissions across their respective regions, and confirms the disinflationary environmental logic underlying Ecological Modernization Theory, whereby expanding cleaner energy sources can decouple continued energy use from environmental harm. The statistically insignificant effect of total energy production and electricity generation echoes the more nuanced, threshold-dependent findings of Adebayo and Kirikkaleli (2025) and Balcilar, Bekun and Usman (2025), who found that the environmental effect of aggregate energy and electricity variables often depends on the underlying fuel mix and level of industrial development rather than on scale alone. The significant negative effect of fossil fuel energy production, while contrary to a priori expectation and to the positive fossil-fuel effects reported by Alajmi (2024) and Ozturk and Ullah (2024), may be attributable to improvements in Nigeria's associated gas capture and flare-reduction initiatives in the more recent years of the study period. Similarly, the significant negative urbanization effect, while contrary to the positive urbanization-emissions relationship reported by Wang, Zhang and Li (2024) and Bekun, Alola and Gyamfi (2024), may reflect the comparatively more efficient energy infrastructure of Nigeria's urban centres relative to its rural and peri-urban areas. Overall, the results reinforce the Environmental Kuznets Curve's ascending-segment logic for Nigeria's aggregate energy-emissions relationship, while confirming that renewable energy consumption, specifically, offers a statistically reliable, disinflationary pathway toward improved environmental quality.

Conclusion and Recommendations

Conclusion

This study examined the effect of energy production on environmental quality in Nigeria from 1990 to 2025, using the ARDL bounds testing approach. The study found that renewable energy consumption, fossil fuel energy production, and urbanization exert a negative and statistically significant effect on carbon dioxide emission in the long run, while total energy production and electricity generation exert a negative but statistically insignificant effect. The study concludes that energy production has a substantial impact on environmental quality in Nigeria.

Recommendations

1. The Federal Government of Nigeria, through the Federal Ministry of Power and the Energy Commission of Nigeria, should intensify investment in renewable energy infrastructure such as solar, wind, and hydroelectric power projects, given renewable energy consumption's significant and reliable emission-reducing effect.
2. The Nigerian National Petroleum Company Limited and the Nigerian Upstream Petroleum Regulatory Commission should implement environmentally friendly fossil fuel technologies, improve gas-flaring reduction policies, and promote carbon capture in oil and gas activities, to sustain and extend the recent gains reflected in the significant negative fossil fuel production coefficient.
3. The Transmission Company of Nigeria and the Nigerian Electricity Regulatory Commission should upgrade electricity generation and transmission facilities, prioritising low-carbon generation sources and minimising transmission losses across the national grid.
4. The Federal Ministry of Environment and state urban development authorities should promote sustainable urban planning, including green transportation, energy-efficient housing, waste recycling, and urban afforestation programmes, to consolidate the observed environmental efficiency gains associated with Nigeria's urban centres.

5. The National Bureau of Statistics, the Energy Commission of Nigeria, and relevant research institutions should strengthen the monitoring and reporting of environmental and energy data, to support the design of future, evidence-based energy and environmental policy.

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