Energy Consumption, Economic Growth, and Environmental Quality in Nigeria: Evidence from a Threshold Regression Approach.

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.910000388

Received: 12 October 2025; Accepted: 20 October 2025; Published: 13 November 2025

ABSTRACT

Nigeria's economic growth is closely tied to its energy consumption, which remains heavily dependent on nonrenewable sources, particularly petroleum, to drive industrial and commercial activities. While this reliance has fueled economic growth and strengthened Nigeria's position as a significant oil producer, it has simultaneously intensified environmental degradation. This study examines the interrelationships between energy consumption, economic growth, urbanization, and environmental quality in Nigeria using annual time series data from 1971 to 2020. Employing an autoregressive threshold (ART) testing approach, the analysis captures potential nonlinear dynamics among these variables. The results indicate that the initial phase of fossil fuel consumption contributes to slight improvements in environmental quality; however, long-run dependence on fossil energy significantly deteriorates ecological conditions through pollution and greenhouse gas emissions. The study highlights the urgent need for a structured transition toward renewable energy sources to improve environmental sustainability. Despite Nigeria's low adoption of renewable technologies, the findings provide valuable insights for policymakers to promote clean energy and foster sustainable economic growth.

Keywords: Energy consumption; Economic growth; Renewable energy; Environmental quality; Autoregressive threshold model; Nigeria

INTRODUCTION

Environmental sustainability has become a global priority as economies strive to balance growth with ecological preservation (Oteng-Abayie et al., 2022; Muazu et al., 2023). The intensifying challenge of climate change driven primarily by rising greenhouse gas (GHG) emissions, particularly carbon dioxide emission (CO_2) has highlighted the urgent need for sustainable energy transitions. Human activities such as fossil fuel combustion and deforestation remain the dominant sources of CO_2 emissions worldwide (Shafiei, 2013; Raihan et al., 2022). Conventional energy sources, including coal, oil, and natural gas, continue to account for the majority of global GHG emissions, posing significant threats to planetary stability.

According to the Global Carbon Project, global temperatures are projected to rise by approximately 1.5°C between 2030 and 2052 if current emission trends persist (Keramidas et al., 2020). The consequences of this warming are far-reaching, encompassing desert expansion, sea-level rise, and accelerated glacial melting (Kounetas, 2018). As CO_2 emissions are the main driver of these changes, their reduction is central to achieving environmental sustainability (Abbass et al., 2022). Addressing this challenge requires individual, national, and collective global actions aimed at mitigating environmental degradation and promoting cleaner energy alternatives.

In recognition of the urgency of climate change, several international institutions and agreements have been established. The Intergovernmental Panel on Climate Change (IPCC), founded in 1988 through the collaboration of the United Nations Environment Programme (UNEP) and the World Meteorological

Organization (WMO), serves as the foremost authority on global climate assessments. With 195 member countries, the IPCC provides a scientific foundation for climate-related decision-making and fosters international cooperation. Similarly, the Kyoto Protocol adopted in 1997 as part of the United Nations Framework Convention on Climate Change (UNFCCC), represents a landmark global commitment to reducing GHG emissions. By 2013, 192 countries, including Nigeria, had ratified the Protocol, underscoring worldwide recognition of the shared responsibility to combat climate change.

Nigeria presents a unique case in the global energy–environment nexus. The country's energy consumption patterns substantially influence environmental quality and economic performance. Nigeria relies predominantly on fossil fuels, especially petroleum and natural gas, to meet its energy demands (Oyedepo, 2012). The extraction, refining, and combustion of these fuels release large quantities of pollutants, such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), and carbon dioxide (CO_2). These emissions degrade air quality, particularly in urban centers, and contribute to respiratory and cardiovascular health issues (Heinrich et al., 2020). Moreover, Nigeria's dependence on fossil fuels for electricity generation, transportation, and industrial activity intensifies its contribution to global warming (Oyedepo, 2012; Atedhor, 2023). The resulting climatic changes, manifested through altered rainfall patterns, flooding, droughts, and rising sea levels, pose significant threats to agriculture, water resources, and biodiversity.

The relationship between energy consumption and environmental degradation is both complex and context-dependent. High fossil fuel consumption aggravates CO_2 emissions and air pollution, while increased use of renewable energy can introduce other environmental trade-offs, such as methane emissions from biomass sources. Economic activities, trade openness, and urbanization further shape this dynamic relationship. In Nigeria, rapid industrialization and urban growth have amplified energy demand, intensifying environmental pressures through deforestation, water contamination, and GHG emissions. Despite possessing abundant renewable resources, including solar and wind potential, Nigeria's energy system remains dominated by nonrenewable sources—highlighting a critical need for sustainable energy reform.

Nigeria's energy consumption has been increasing at an average annual rate of 1.7%, reaching approximately 1.54 quadrillion BTUs in 2017 and accounting for about 0.26% of global energy consumption. Projections indicate continued growth, with total demand expected to reach 168 million tonnes of oil equivalent by 2022. These figures underscore the urgency of transitioning toward cleaner energy alternatives to mitigate environmental degradation and promote long-term economic resilience.

This study contributes to the existing literature in three significant ways. First, it provides a comprehensive, country-specific analysis of the relationship between energy consumption and environmental quality, a topic of vital relevance given Nigeria's energy dependence. Second, it examines the ecological footprint of energy use within the broader framework of economic growth, with particular attention to the Nigerian context. Third, it employs a threshold regression approach to capture nonlinearities and regime shifts in the energy–environment relationship—an advancement over traditional linear models that often overlook such complexities.

The threshold model enables the identification of critical points beyond which the effects of energy consumption on environmental quality change in magnitude or direction. This methodology accounts for potential nonlinearity arising from varying energy use patterns and policy regimes. It also addresses common econometric challenges, including heterogeneity, misspecification, and multicollinearity, that have limited the robustness of previous empirical studies.

By integrating these methodological refinements, the study provides new insights into the dynamic interactions among energy consumption, economic growth, and environmental quality in Nigeria. The findings are expected to guide policymakers in designing strategies that balance energy needs with environmental sustainability, ultimately contributing to the country's transition toward a low-carbon, resilient economy.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

THEORY AND LITERATURE REVIEW

Theoretical Framework

The theory of energy consumption represents a core concept in energy economics, focusing on patterns, determinants, and implications of energy use within economic and societal contexts. The central premise is that energy is a finite and essential input for economic production and social welfare, requiring efficient utilization to achieve sustainable growth (Vosooghzadeh, 2020). Both individuals and firms are assumed to act rationally, optimizing their energy use to maximize output or utility given resource constraints.

Multiple factors, including population growth, income levels, technological advancement, and policy interventions, shape energy demand. Population growth is particularly critical, as expanding populations heighten the demand for energy services such as heating, cooking, transportation, and electricity (Gershon et al., 2022; OECD, 2016). This rising demand necessitates adaptive strategies to manage limited energy resources efficiently and mitigate environmental pressures.

Economic conditions also play a defining role in shaping energy use. Industrial expansion driven by economic growth often increases the energy intensity of production processes, particularly in manufacturing and transportation sectors. As economies develop, energy consumption tends to rise proportionally, reflecting higher living standards and industrial output (Sovacool & Hess, 2017). However, higher energy prices can incentivize efficiency improvements and investment in cleaner technologies, emphasizing the importance of economic instruments and policy frameworks in promoting sustainable energy consumption.

In summary, the theory of energy consumption provides a valuable analytical framework for understanding the behavioral, economic, and structural determinants of energy demand, highlighting the interdependence between energy use, technological progress, and sustainability outcomes.

Empirical Literature Review

A substantial body of research has explored the interrelationship between energy consumption, economic growth, and environmental quality, though results vary across countries and methodologies. Most early studies examined the energy–growth nexus**,** while more recent works extend the analysis to include CO_2 emissions and environmental sustainability**.** In Nigeria, Adeniran (2009) identified a unidirectional causality running from GDP to electricity consumption using the Granger causality test, indicating that economic growth drives energy demand. Similarly, Dantama et al. (2012) found that electricity and petroleum consumption significantly promote long-run economic growth, while coal use remains insignificant. However, the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental degradation initially worsens with growth before improving, was not supported. Akpan & Akpan (2012) further revealed that rising carbon emissions negatively affect growth, reinforcing the argument that fossil fuel dependence undermines sustainable development. Beyond Nigeria, Alshehry & Belloumi (2015) established a long-run bidirectional relationship between energy use and economic growth in Saudi Arabia using Johansen's cointegration approach. Saidi & Hammami (2015) expanded the analysis globally, finding that both CO_2 emissions and economic growth significantly influence energy consumption across 58 countries from 1990 to 2012. However, the strength of the relationship varies by region.

In the European context, Streimikiene & Kasperowicz (2016) reported a long-run cointegrating relationship among energy consumption, GDP, fixed capital, and employment in 18 EU countries. Likewise, Mirza & Kanwal (2017) identified long- and short-run linkages between energy use, carbon emissions, and growth in Pakistan using ARDL and VECM techniques. In the South Caucasus and Turkey, Magazzino (2017) observed a negative and statistically significant relationship between CO_2 emissions and energy use, implying potential decoupling in the long term. Sulaiman & Abdul-Rahim (2018) found that in Malaysia, although CO_2 emissions do not directly affect growth, they increase with higher energy use and economic activity. Similarly, Salahuddin & Gow (2019) revealed that energy consumption and financial development substantially influence environmental degradation in Qatar. Using cross-country data, Osobajo et al. (2020) demonstrated a positive correlation between energy use, economic growth, and CO_2 emissions across 70 nations from 1994 to 2013.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Magazzino et al. (2021), analyzing 80 years of Italian data through wavelet analysis, concluded that the energy–growth relationship is primarily short-run and bidirectional across all frequency bands.

In Sub-Saharan Africa and West Africa, Onuoha et al. (2022) employed a Panel Nonlinear ARDL model to assess energy access and environmental quality across 15 ECOWAS countries. Their results demonstrate that nonrenewable energy consumption harms environmental and agricultural sustainability, underscoring the need for renewable alternatives. Similarly, Dimnwobi et al. (2021) highlighted the transformative potential of cleaner energy technologies to mitigate health and environmental risks associated with fossil fuel dependence in African economies. Focusing on Nigeria, Rafindadi (2016) observed that the country's energy consumption remains dominated by fossil fuels. Economic growth exerts both direct and indirect effects on environmental degradation, depending on the energy mix and efficiency levels. Additionally, Wang et al. (2018) identified urbanization and population growth as major drivers of rising energy demand and CO_2 emissions globally, an observation particularly relevant to Nigeria's rapid demographic and urban expansion.

Collectively, these studies affirm the complex and context-specific interactions among energy consumption, economic growth, and environmental outcomes. However, much of the existing literature focuses primarily on CO_2 emissions as the sole indicator of environmental degradation. Few studies comprehensively examine broader ecological quality indicators or consider the threshold effects of fossil fuel consumption in developing economies such as Nigeria. Despite extensive global research, empirical evidence on the nonlinear and threshold effects of energy consumption on environmental quality in Nigeria remains limited. Existing studies often rely on linear models that overlook regime shifts or dynamic changes in energy use patterns. Moreover, methodological challenges such as heterogeneity, endogeneity, and multicollinearity further constrain the robustness of prior findings.

This study addresses these gaps by employing a threshold regression model to analyze how the relationship between energy consumption, economic growth, and environmental quality varies across different levels of fossil fuel use. By capturing potential nonlinearities and structural shifts, the research contributes novel insights to the energy–environment literature, providing policymakers with evidence-based guidance for promoting renewable energy adoption and sustainable economic development in Nigeria.

METHODOLOGY AND DATA

This study examines the impact of energy consumption and economic growth on environmental quality in Nigeria, with energy consumption serving as a key threshold variable. Annual time-series data covering the period 1971–2020 were obtained from the World Development Indicators (WDI) of the World Bank to ensure accuracy and consistency. The variables include ecological footprint (EF) as a measure of environmental quality, energy consumption (EN), population growth rate (PO), trade openness (TR), gross domestic product per capita (Y) and square gross domestic product per capita (Y^2).

Threshold Regression Approach

To capture possible nonlinear dynamics and regime-switching behavior in the relationship between energy consumption and environmental quality, the study employs the Self-Exciting Threshold Autoregressive (SETAR) framework proposed initially by Tong (1977) and Tong & Lim (1980). The SETAR model allows parameter values to change once an observable variable (in this case, energy consumption) crosses an identified threshold, thereby differentiating between low- and high-energy consumption regimes.

The general form of a SETAR(p) model can be represented as:

$$y_t = \begin{cases} \phi_1' X_t + \varepsilon t, \text{ if } z_t - d \leq \gamma \\ \phi_2' X_t + \varepsilon t, \text{ if } z_t - d \leq \gamma \end{cases} \quad (1)$$

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

where y_t denotes the dependent variable (ecological footprint), X_t is a vector of regressors including lagged values of the dependent and explanatory variables, z_t−d is the threshold variable (lagged energy consumption), γ is the estimated threshold value, and ε_t is a white-noise error term.

This model is particularly suited for identifying whether the impact of energy consumption on environmental quality differs between low and high energy-use regimes, providing more nuanced insights than linear specifications.

Threshold Cointegration and Error Correction

To examine the long-run equilibrium relationships among the variables, the study employs the Threshold Autoregressive Cointegration (TAR) and Error Correction Model (ECM) frameworks. The TAR model extends the conventional autoregressive process by allowing different adjustment dynamics across regimes, while the ECM captures both short-run fluctuations and long-run equilibrium tendencies.

$$X_t = \alpha_0^{(Jt)} + \sum_{1-i}^{p} \alpha^{(Jt)} X_{t-i} + b^{(Jt)} \varepsilon_t \quad (2)$$

The general error-correction specification is given as:

$$\Delta \ln EF_t = \beta_0 + \sum_{i-1}^{p} \beta_i X_{i-1} + \partial ECM_{i-1} + \mu_t \quad (3)$$

where Δ represents the first-difference operator, ECM_{t-1} is the lagged error correction term, and δ indicates the speed of adjustment toward long-run equilibrium. A negative and statistically significant δ confirms the presence of cointegration among the variables.

To test for cointegration, the Wald F-statistic is computed and compared against the critical values of Narayan's (2005) bounds test. If the computed F-statistic exceeds the upper bound, cointegration is confirmed; if below the lower bound, no cointegration exists; and if it lies between bounds, the result is inconclusive.

Model Specification

The empirical analysis is grounded in the energy consumption theory, which posits that the amount and efficiency of energy use in productive activities directly influence economic performance. Accordingly, the general functional form of the model is expressed as:

$$EF_t = f(EN_t, PO_t, TR_t, Y_t, Y_t^2) \quad (4)$$

Equation (4) captures the hypothesized nonlinear relationship between economic growth and environmental degradation, consistent with the Environmental Kuznets Curve (EKC) framework. To ensure comparability and reduce heteroskedasticity, all variables are transformed into natural logarithms, yielding the following log-linear econometric form:

$$\ln EF_t = \alpha_0 + \alpha_1 \ln EN_t + \alpha_2 \ln PO_t + \alpha_3 \ln TR_t + \alpha_4 \ln Y_t + \alpha_5 (\ln Y^2{}_t) + \varepsilon t \quad (5)$$

where α_0 denotes the intercept, αi (for i = 1…5) are slope coefficients, and εt is the stochastic error term.

Justification for Methodology

The threshold regression and cointegration approaches were chosen for their capacity to handle structural changes, regime shifts, and potential nonlinearities in the energy–environment relationship, issues often overlooked by traditional linear models. This framework allows for a more realistic understanding of how varying levels of energy consumption affect Nigeria's environmental quality, providing robust evidence for sustainable policy formulation.

RESULTS AND DISCUSSION

Unit Root Tests

Before conducting the ARDL cointegration analysis, it is essential to examine the stationarity properties of the time series data to determine the order of integration of each variable. This step ensures that no variable is integrated of order two or higher, as the ARDL approach requires all series to be either I(0) or I(1). To achieve this, both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were employed to check for the presence of unit roots in the variables. These complementary tests help to validate the robustness of the stationarity results by addressing possible serial correlation and heteroskedasticity issues in the residuals. The outcomes of the ADF and PP tests are presented in Table 1 below.

Table 1: Results of ADF and PP Unit Root Tests

Variables	ADF		PP		
	Level				
	t-stat.	P-Value	t-stat.	P-Value	Status
LNEF	-1.213	0.896	-1.089	0.920	
LNEN	-2.414	0.367	-2.753	0.072	I(0)
LNFF	-4.447	0.004	-4.553	0.003	I(0)
LNPO	-2.892	0.173	-2.843	0.059	I(0)
LNY	-1.377	0.855	-1.211	0.897	
Y2	-1.245	0.889	-1.202	0.898	
LNTR	-2.345	0.402	-2.603	0.280	
	First Difference				
	t-stat.	P-Value	t-stat.	P-Value	
LNEF	-7.587	0.000	-7.604	0.000	I(1)
LNEN	-6.390	0.000	-6.565	0.000	I(1)
LNFF	-5.524	0.000	-5.488	0.000	I(1)
LNPO	-4.844	0.001	-4.924	0.001	I(1)
LNY	-3.234	0.001	-5.513	0.000	I(1)
Y2	-5.835	0.000	-5.906	0.000	I(1)
LNTR	-7.378	0.000	-7.361	0.000	I(1)

Note: SIC is used in ADF test and both intercept and trend are used

Correlation Matrix Analysis

Table 2 presents the correlation matrix for the explanatory variables, computed using the Pearson correlation coefficient. The correlation matrix serves as an important statistical tool to assess the strength and direction of linear relationships among variables and to detect potential multicollinearity issues within the regression model. Multicollinearity occurs when two or more independent variables are highly correlated, which can distort the precision of estimated coefficients and reduce model reliability. Following the guideline proposed by Abaidoo & Agyapong (2023)**,** a correlation threshold of 0.85 was adopted to identify possible multicollinearity concerns. The results reveal that none of the correlation coefficients exceed this threshold, indicating that multicollinearity is not a problem in the model. Hence, the explanatory variables can be reliably included in subsequent regression analyses.

Table 2: Descriptive Statistics and Correlation Matrix

	LNEF	LNEN	LNFF	LNPO	LNY	Y2	LNTR
Mean	0.028	6.552	2.860	0.969	7.531	3826995	3.417
Median	0.031	6.549	2.944	0.962	7.556	3661171	3.536
Maximum	0.212	6.683	3.128	1.119	7.897	7226781	3.975
Minimum	-0.213	6.361	1.786	0.814	7.236	1928029	2.212
Std. Dev.	0.092	0.080	0.289	0.064	0.222	1687842	0.465
Skewness	-0.416	-0.613	-2.321	0.401	0.103	0.505	-1.207
Kurtosis	3.224	2.745	7.775	3.329	1.562	1.970	3.646
Jarque-Bera	1.547	3.267	92.408	1.566	4.395	4.336	13.009
Probability	0.461	0.195	0	0.457	0.111	0.114	0.001
LNEN	1						
LNFF	0.201	1					
LNPO	0.621	0.303	1				
LNY	-0.265	-0.181	0.198	1			
Y2	-0.360	-0.117	0.136	0.986	1		
LNTR	0.201	0.017	0.375	0.303	0.255	1	

Source: Authors computation based on data from World Development Indicators (WDI)

Table 3: Threshold analysis

Dependent variable: Ecological footprint							
Panel A : Estimates							
Regime 1 (LNEF(-2) < -0.025 obs (8 Obs)				Regime2 -0.025 <= LNEF(-2) -- 40 obs			
Var	Coeff	T-stat	Prob	Var	Co eff	T-stat	prob
LNEN	-0.090	-0.525	0.601	LNEN	0.578	4.774	0.000***
C	-6.702	-3.142	0.003	C	-11.059	-6.100	0.000

Non-Threshold Variables

Variable	Coefficient	Std. error	T. star	Prob
LNPO	0.788	0.150	5.247	0.000***
LNTR	-0.024	0.015	-1.587	0.120
LNY	0.954	0.220	4.325	0.001***
Y2	-1.48E-0	2.90E-0	-5.112	0.000***
Panel B : Diagnostic test				

Jarque Bera 0.9811

Serial correlation 0.8037

Heteroscedasticity 0.5625

Ramsey rest test 0.4167

Note: ** p < 0.05, ***p < 0.01, and *p < 0.1 denotes 1%, 5% and 10% level of significance.

Table 4: Threshold analysis

Dependent variable : Ecological footprint							
Panel A : Estimates							
Regime 1 (LNEF(-2) < 0.031 (23 Obs)				Regime2 0.031 <= LNEF(-2) 25 obs			
Var	Coeff	T-stat	Prob	Var	Co eff	T-stat	prob
LNFF	0.002	0.046	0.963	LNFF	0.284	4.101	0.000***
C	-5.229	-3.071	0.003	C	-6.012	-3.620	0.000

Non-Threshold Variables

Variable	Coefficient	Std. error	U. star	Prob
LNPO	0.686	0.141	4.843	0.000***
LNTR	0.018	0.015	1.212	0.232
LNY	0.650	0.244	2.664	0.011**
Y2	-1.06E	3.11E	-3.399	0.000***
Panel B : Diagnostic test				

Jarque Bera 0.8870

Serial correlation 0.3731

Heteroscedasticity 0.9313

Ramsey rest test 0.5982

Note: ** p < 0.05, ***p < 0.01, and *p < 0.1 denotes 1%, 5% and 10% level of significance.

The tables above present the outcomes of the threshold regression analysis. The autoregressive threshold model is a nonlinear regression technique in which the coefficients vary depending on whether the threshold variable lies above or below a specific parameter value. This study adopts a single-threshold specification with two distinct regimes to capture possible nonlinear dynamics between energy consumption, fossil fuel use, and environmental quality. The ecological footprint serves as the dependent variable, representing environmental quality, while energy consumption and fossil fuel use act as the key threshold variables. The first regime captures periods when energy and fossil fuel consumption fall below the estimated thresholds of –0.025 and 0.031, respectively. In contrast, the second regime reflects instances when these levels meet or exceed the threshold limits.

The two-regime specification was selected to identify the point at which population growth and per capita income begin to exacerbate environmental degradation through increased energy demand. Results from Table 3 indicate that when energy and fossil fuel consumption remain below the thresholds, energy use exerts a negative but statistically insignificant impact on environmental quality. However, when fossil fuel consumption surpasses these thresholds, energy use demonstrates a positive and significant influence, implying

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

that environmental quality improves only after a certain level of energy efficiency or institutional enforcement is achieved. Specifically, below the threshold, energy use reduces environmental quality by –0.09%, whereas above the threshold, energy consumption enhances ecological sustainability.

The findings further suggest that both energy consumption and fossil fuel use contribute to environmental deterioration below the critical thresholds. Nigeria's growing population, coupled with rising income levels, has intensified energy demand, often met through non-renewable sources, leading to ecological degradation. The results imply that environmental quality must first reach a minimum sustainable level before additional energy use can yield environmental benefits. Moreover, when consumption remains below the thresholds, economic and population growth reinforce unsustainable environmental practices, reflecting the country's persistent reliance on fossil fuels and insufficient investment in renewable alternatives.

Over the study period, Nigeria consistently operated below the identified thresholds, indicating a progressive decline in environmental quality linked to fossil fuel dependence. This pattern highlights the country's prioritization of short-run economic growth over environmental conservation. The growing accessibility of finance and credit has also fueled energy demand across sectors, particularly transportation, exacerbating emissions and pollution levels.

The analysis reveals a threshold level of 1.3397% in the energy mix, below which increases in renewable energy output paradoxically raise fossil fuel use, emphasizing Nigeria's ongoing dependence on conventional energy sources (Akorede & Afroz, 2020). When non-renewable energy production remains high, it significantly contributes to environmental degradation. Thus, performance above the renewable threshold is essential to reversing these effects.

Empirically, results from Regime 2 indicate that a 1% rise in energy use leads to a 0.578% increase in environmental degradation, while fossil fuel consumption increases the ecological footprint by 0.284%. Although Regime 1 also shows positive associations, these effects are statistically insignificant. These findings validate the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995; Shafik, 1994), suggesting a U-shaped relationship between income and environmental degradation, where pollution rises during early economic growth but declines after reaching a development threshold. This evidence aligns with prior Nigerian studies by Omisakin (2009), Chuku (2011), Aiyetan & Olomola (2017), and Okeke (2021).

Diagnostic tests (Panel B, Threshold Tables) confirm the robustness of the results. The residuals are normally distributed, homoscedastic, and free from serial correlation, as validated by the Breusch–Pagan, LM, and Ramsey RESET tests. This confirms that the models are structurally sound and statistically reliable. The graphical representations illustrate variable dynamics, reflecting, among other influences, the impact of Nigeria's Environmental Impact Assessment Act of 1992, which sought to enforce accountability in public and private projects.

Finally, an OLS robustness test (Tables 5 and 6) reaffirms the threshold regression results, showing a positive relationship between ecological footprint energy usage and fossil fuel consumption, population growth, and GDP per capita, but a negative relationship with GDP per capita squared. These outcomes strengthen the empirical validation of the EKC hypothesis and emphasize that sustainable energy policy, population management, and institutional reform are vital for improving Nigeria's environmental quality.

Table 5: Impact of energy consumption on environmental quality Using OLS

Dependent variable = Ecological footprint (lnEF): Regressor		
Energy consumption (ln**EN**)	0.348*** (0.002)	3.166
Population growth (ln**PO**)	0.736*** (0.005)	5.932

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Trade openness (ln**TR**)	-0.015 (0.391)	-0.864
GDP per capita (ln**Y**)	1.198*** (.0.000)	4.926
GDP per capita (**Y^2**)	-1.84E (0.000)	7.3200
Consant (C)	-11.241*** (0.000)	0.6137

Note. Parentheses are the t-statistics. OLS = ordinary least square ***, **, * Indicates significant at 1%, 5% & 10 level.

Table 6: Impact of energy consumption on environmental quality Using OLS

Dependent variable = Ecological footprint (lnEF): Regressors		
Fossil fuel consumption (lnFF)	0.060* (0.085)	1.757
Population growth (ln**PO**)	0.637*** (0.000)	4.076
Trade openness (ln**TR**)	-0.001 (0.934)	-0.833
GDP per capita (ln**Y**)	1.098 (0.000)	3.939
GDP per capita (**Y^2**)	-1.64E*** (0.000)	-4.638
Consant (C)	-8.402*** (0.000)	-4.342

Note. Parentheses are the t-statistics. OLS = ordinary least square ***, **, * Indicates significant at 1%, 5% & 10 level.

The findings align with the strong outcomes derived from the estimated models, thus supporting the validity of the empirical results. This analysis validates the findings of the Autoregressive Threshold (ART) model, indicating that the variables studied are significant predictors of Nigeria's ecological footprint. The threshold dynamics indicate that changes in energy consumption, population growth, and economic growth have significant and nonlinear impacts on environmental quality. The findings indicate that, beyond specific threshold levels, increases in these variables are associated with declines in environmental conditions, as evidenced by elevated ecological degradation. This indicates that Nigeria's environmental quality is vulnerable to changes in economic and demographic activities, particularly amid increasing energy demand. Therefore, it is crucial to manage these factors within sustainable limits to attain long-term environmental sustainability and to align economic growth with ecological preservation.

CONCLUSION AND POLICY RECOMMENDATIONS

The study presents empirical evidence regarding the interactions among energy consumption, economic growth, population growth, and environmental quality in Nigeria from 1971 to 2020. The findings align with the models' robustness outcomes, thereby confirming the validity of the autoregressive threshold approach.

The findings indicate that energy consumption, population growth, and economic development are the main factors influencing environmental quality in Nigeria, aligning with previous research by Adewuyi & Awodumi (2020) and Alola et al., (2021).

The threshold autoregression findings reveal a significant level of energy consumption that affects the relationship between economic growth and environmental degradation. Economic expansion and population growth below this threshold negatively affect environmental quality, primarily due to heavy dependence on fossil fuels and unsustainable production methods (Adewuyi et al., 2023). In contrast, trade openness enhances environmental performance by enabling technology transfer and encouraging the implementation of energy-efficient systems (Nathaniel & Iheonu, 2019; Bello et al., 2021). Energy consumption is a significant factor in economic development; however, it concurrently poses challenges to environmental sustainability, a relationship extensively explored in recent empirical studies (Alola et al., 2021; Odugbesan & Rjoub, 2020).

Several implications arise from a policy perspective. The Nigerian government, alongside environmental agencies such as the National Environmental Standards and Regulations Enforcement Agency (NESREA), should enhance institutional capacity to monitor and enforce environmental regulations to reduce CO_2 emissions effectively. Regular inspections of energy activities in both the industrial and residential sectors are crucial to ensuring compliance with environmental standards. Policymakers should prioritize significant investment in renewable energy specifically solar, wind, and hydro power to diversify Nigeria's energy mix and reduce reliance on fossil fuels. Third, the provision of financial, fiscal, and regulatory incentives is essential to promoting private-sector involvement in cleaner technologies and sustainable industrial practices.

Additionally, these policy interventions should be systematically aligned with Nigeria's Renewable Energy Master Plan (REMP) and the United Nations Sustainable Development Goals (SDGs) specifically Goals 7 (Affordable and Clean Energy), 13 (Climate Action), and 8 (Decent Work and Economic Growth). This alignment will improve the policy relevance of these measures, reinforce Nigeria's commitment to global sustainability frameworks, and promote a transition to a low-carbon, resilient economy.

This study highlights the need for Nigeria to reconcile economic growth with environmental sustainability by implementing effective energy transition policies, fostering technological innovation, and complying with international environmental commitments. Implementing these recommendations will reduce emissions and enhance long-term ecological stability and economic resilience.

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ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

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