Population Dynamics and Carbon Emissions in Nigeria: Re-Examining the Population–Environment Nexus in Nigeria

[1]Fiala, T., [2]Momodu, A. A., [3]Nwikina, C. G & [4]Njoku, K.C
Department of Economics,
[1,2,3,&4]Rivers State University, Port Harcourt,
Rivers State, Nigeria.
tuboalabo.fiala@ust.edu.ng
https://doi.org/10.56201/jbae.vol.12.no10.2026.pg54.65

Abstract
This study examined the determinants of carbon dioxide (CO_2) emissions in Nigeria, focusing on population growth, urbanization, GDP per capita growth, and energy consumption per capita. The study employed annual data covering 1990–2024, sourced from the World Development Indicators (WDI) and the United Nations Development Programme (UNDP). The study employed the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) unit root test, the Autoregressive Distributed Lag (ARDL) bounds testing approach for cointegration, and post-estimation diagnostic and robustness checks. The KPSS results confirmed that the variables exhibit mixed orders of integration, I(0) and I(1), justifying the application of the ARDL framework. The bounds test further confirmed the existence of a long-run relationship among the variables. The results indicate that population growth has a positive but statistically insignificant long-run effect on CO_2 emissions, while urbanization has significant short-run effects but an insignificant negative long-run effect. GDP per capita growth has a negative and statistically significant long-run effect, whereas energy consumption per capita has a positive and statistically significant long-run effect on CO_2 emissions. The error-correction term indicates that approximately 65% of short-run disequilibrium is corrected within one period. Overall, the findings underscore the importance of clean energy transition, energy efficiency, and sustainable urban development in reducing CO_2 emissions while supporting Nigeria's economic development.

Keywords: *CO_2, population growth; urbanization; GDP per capita; energy consumption; ARDL; Nigeria.*

1. Introduction

The population–environment nexus has attracted considerable attention in environmental and development economics because demographic expansion can increase demand for energy, infrastructure, transportation, and other resource-intensive activities. However, the environmental consequences of population change are not necessarily proportional to population growth, as they are mediated by economic development, urbanization, energy use, and technological change. The IPAT framework of Ehrlich and Holdren (1971) conceptualizes environmental impact as a function of population, affluence, and technology, while the STIRPAT formulation of Dietz and Rosa (1997) and York et al. (2003) provides a stochastic framework for empirically estimating these effects. This perspective suggests that understanding carbon emissions requires consideration of demographic and socioeconomic factors jointly rather than population growth in isolation.

Nigeria presents an important setting for re-examining this relationship. The country's population increased to approximately 232.7 million in 2024, while about 63% of the population resided in urban areas, reflecting the scale and continuing transformation of its demographic structure (World Bank, 2026a, 2026b). At the same time, GDP per capita growth remained an important dimension of Nigeria's economic transformation, although improvements in aggregate economic activity have not necessarily translated into comparable gains in per-capita living standards (World Bank, 2026c). These demographic and economic developments have important environmental implications because population expansion and urbanization can increase energy demand and economic activity, thereby creating additional pressure on carbon emissions.

The development context further illustrates this challenge. UNDP data show that Nigeria's Human Development Index (HDI) increased from 0.379 in 1990 to 0.560 in 2023, indicating substantial improvement in human development over the study period, although Nigeria remains in the medium-human-development category (UNDP, 2025a, 2025b). This progress has occurred alongside persistent development needs, creating a policy challenge of improving welfare while limiting environmental degradation. Energy consumption is particularly relevant to this challenge because it represents a major channel through which population and economic activity can translate into carbon emissions. Evidence for Nigeria indicates that urbanization has implications for electricity consumption and economic activity (Ali et al., 2020), while Rafindadi (2016) finds that energy consumption significantly increases CO_2 emissions in Nigeria.

Despite these theoretical and empirical considerations, evidence concerning the population–environment relationship in Nigeria remains inconclusive. Akinlo (2009), applying the STIRPAT framework, found population, affluence, and urbanization to be significant determinants of environmental impact in Nigeria. Similarly, recent evidence indicates that energy consumption and urbanization contribute to environmental degradation, while also providing support for the Environmental Kuznets Curve (EKC) hypothesis in Nigeria (Yusuf, 2023). These findings nevertheless differ in their magnitude and, in some cases, direction across variables and study periods, suggesting that the relationship may be sensitive to model specification, measurement, and changes in Nigeria's economic and demographic structure.

The unresolved nature of these relationships constitutes the central problem addressed in this study. Nigeria must accommodate a rapidly growing population, expanding urban settlements, rising energy requirements, and the pursuit of higher living standards while simultaneously limiting carbon emissions. Existing studies have examined several dimensions of this nexus, but relatively limited attention has been given to the joint effects of population growth, urbanization, GDP per capita growth, and energy consumption per capita on CO_2 emissions per capita over the recent period of Nigeria's demographic and economic transformation.

Against this background, this study re-examines the population–environment nexus in Nigeria over 1990–2024, examining the effects of population growth rate, urbanization rate, GDP per capita growth, and energy consumption per capita on CO_2 emissions per capita. By integrating demographic, economic, and energy dimensions within a unified framework, the study provides updated evidence on the mechanisms through which population dynamics influence environmental pressure in Nigeria and contribute to the policy debate on reconciling human development with environmental sustainability.

2. Literature Review

IPAT Theory

Ehrlich and Holdren (1971) proposed the IPAT identity, which conceptualizes environmental impact as a function of population (P), affluence (A), and technology (T): (I = PAT). The theory assumes that environmental degradation is jointly determined by the scale of the population,

the level of consumption or income per person, and the technology used to produce goods and services. Population expansion increases the scale of human activities, while rising affluence increases consumption and resource demand; technology determines the environmental intensity of production and consumption. The IPAT framework therefore provides the broad theoretical basis for examining how population growth, economic development, and energy-related technological characteristics influence environmental pressure. For the present study, population growth represents the demographic dimension, GDP per capita growth captures affluence, and energy consumption provides an important channel through which economic activity can translate into CO_2 emissions.

STIRPAT Model

Dietz and Rosa (1997) developed the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model as a stochastic extension of the deterministic IPAT identity. Subsequently, York, Rosa, and Dietz (2003) further developed its empirical application. STIRPAT assumes that environmental impacts can be statistically estimated as a function of population, affluence, and technology while allowing the effects of these determinants to be independently estimated and statistically tested. Unlike IPAT, which imposes a fixed multiplicative relationship among its components, STIRPAT permits flexible coefficients and the incorporation of additional explanatory variables. This makes it particularly appropriate for empirical analysis of the population–environment nexus. In the present study, population growth and urbanization capture demographic pressures, GDP per capita growth represents affluence, while energy consumption per capita represents an important technological and energy-use channel through which socioeconomic activity may affect CO_2 emissions.

Environmental Kuznets Curve (EKC) Hypothesis

Grossman and Krueger (1995) advanced the Environmental Kuznets Curve (EKC) hypothesis, building on the earlier environmental-development arguments of Panayotou (1993). The EKC hypothesis assumes that the relationship between economic development and environmental degradation may follow an inverted-U pattern. At relatively low levels of income, economic expansion tends to increase environmental degradation because growth is accompanied by greater production, resource use, and pollution. Beyond a certain income threshold, however, further development may reduce environmental pressure as economies undergo structural transformation, adopt cleaner technologies, improve energy efficiency, and strengthen environmental regulation. The hypothesis therefore provides a theoretical explanation for a potentially nonlinear relationship between economic development and CO_2 emissions. Although the present study uses GDP per capita growth rather than income level and its squared term, the EKC perspective remains relevant for interpreting whether economic development constitutes a source of additional carbon pressure or facilitates environmental improvement.

Empirical Review

Rehman et al. (2021) aimed to decouple CO_2 emissions from agricultural and environmental variables in Pakistan using time series data from 1970 to 2017. The vector autoregressive model showed that forestry production, rainfall, and temperature increased emissions, while crops, livestock, energy use, and population growth reduced emissions in the long run. Short-run results differed, showing mostly positive effects. Granger causality tests indicated unidirectional relationships among variables.

Wang et al. (2021) provided empirical evidence on the roles of green policy instruments, green energy, green finance, and green innovation in promoting environmental sustainability within BRICS countries from 1995 to 2019. Using the STIRPAT framework alongside second-

generation econometric estimators, the study assessed environmental sustainability through indicators such as CO_2 emissions, ecological footprint, and PM2.5 pollution. The results showed that green energy, green finance, green innovation, and eco-digitalisation reduced ecological footprint and other environmental pollutants, thereby enhancing sustainability. Conversely, urbanisation and affluence increased environmental degradation due to their expansionary effects on pollution. Quantile regression and country-specific estimations confirmed the consistency of these findings across distributions, while Granger causality tests revealed both unidirectional and bidirectional relationships among the variables.

Aninwagu and Nyeche (2024) investigated the impact of renewable energy consumption, forest area, and economic growth on CO_2 emissions in Nigeria. They used renewable energy consumption (REC), forest area as a percentage of land area (FOA), and GDP per capita (GDPC) as independent variables, while CO_2 emissions served as the dependent variable. Time-series data for these variables came from the World Development Indicators (WDI) for the period 1990 to 2023. The analytical methods employed included unit root tests, the Engle-Granger cointegration test, error correction model analysis, and residual diagnostic tests. The augmented Dickey-Fuller (ADF) unit root test results indicated that all variables were integrated of order one, I(1). The error correction model results established a statistically significant and negative relationship between REC and CO_2 emissions. Furthermore, the analysis revealed a positive but statistically non-significant relationship between FOA and CO_2 emissions. Additionally, GDP per capita showed a positive but statistically non-significant effect on CO_2 emissions.

Shaheem et al. (2025) explored the complex relationship between population growth and CO_2 emissions in the context of export-driven activities in the global transportation sector. The study addressed a gap in the literature by examining how demographic trends influenced the environmental impact of international trade. Using a robust dataset of 30 countries from 2011 to 2020, the study employed advanced models to examine the relationships among trade activities, population growth, and CO_2 emissions. The results showed that export activities significantly increased CO_2 emissions due to higher energy consumption associated with production and transportation. Population growth was found to amplify this effect by increasing demand for transportation services, thereby leading to higher emissions.

Ahmed et al. (2023) investigated the impact of energy consumption on CO_2 emissions, influenced by population growth, energy consumption per capita, and income. The study examined whether increases in energy consumption, energy intensity, energy consumption per capita, population growth, and income affected CO_2 emissions in China, India, and the USA. The study applied the non-linear autoregressive distributed lag (NARDL) model and machine learning techniques. The results showed that energy consumption per capita significantly impacted CO_2 emissions in all three countries. Income increases led to higher CO_2 emissions in India but reduced emissions in the USA. Population growth increased emissions only in India. A decrease in energy intensity improved environmental quality in China and India.

Ngong et al. (2022) investigated the relationship between urbanization and carbon dioxide emissions in the Central African Economic and Monetary Community from 1990 to 2019. The literature indicated that the relationship between urbanization and CO_2 emissions remained debatable and that existing findings were inconclusive. In the methodology, CO_2 emissions were treated as the dependent variable, while urbanization, gross domestic product (GDP), financial development (FD), rule of law (ROL), and government effectiveness (GEF) were used as independent variables. The study applied Johansen–Fisher and Kao residual cointegration tests alongside fully modified and dynamic ordinary least squares methods. The results showed a significant positive relationship between urbanization and CO_2 emissions. The causality test results indicated that CO_2 emissions unidirectionally Granger-caused urbanization, GDP, and FD.

Jebli and Chaouali (2025) examined the effect of economic growth (Y, GDP), the service sector (SVA), and renewable and non-renewable energy consumption (RE, NRE) on environmental quality (CO_2, E) and the dynamic interdependence among them for China over the period 1980–2021 using linear and nonlinear autoregressive distributed lag (ARDL, NARDL) techniques. Granger causality tests checked for causalities among the underlying variables. The main results from the ARDL model showed unidirectional causality from GDP to SVA and bidirectional causality between RE and NRE as well as between RE and CO_2 in the short term. However, no short-run causality existed between NRE, E, GDP, and SVA. According to the NARDL results, a one-way causality ran from RE^+ to all variables and from SVA to RE^+. Granger tests also showed bidirectional causality between RE^+ and CO_2 and between RE^+ and NRE in the short run. Nevertheless, a negative shock in renewable energy negatively affected CO_2 emissions in the long term. China's policymakers increased the share of non-fossil fuels in primary energy and invested more in technology within the service sector, including buildings and transport.

Chew et al. (2024) explored the relationships among population growth, GDP, CO_2 emissions, energy consumption, and renewable energy production in Canada from 1950 to 2021. Using time-series econometric techniques such as OLS, VAR, and cointegration analysis, the study found that population and GDP growth increased energy consumption and emissions. While renewable energy growth offered opportunities for reducing emissions, risks of overexploitation were noted.

3. Methodology

This study adopts a quantitative, longitudinal (time-series) research design. The data for this study was sourced from the World Bank's World Development Indicators (WDI) and the United Nations Development Programme (UNDP) from 1990 to 2024.

The study was theoretically anchored on the STIRPAT model, which extends the deterministic IPAT identity (Impact = Population × Affluence × Technology).

The study specifies the following models:

$CO_2 = f\,(POPG, URB, GDPPC, ENEC)$ 3.1

$$CO_{2t} = \beta_0 + \beta_1 POPG + \beta_2 URB_t + \beta_3 GDPPC_t + \beta_4 ENEC_t + \mu_t \quad 3.2$$

$$\Delta CO_{2t} = \alpha_0 + \sum_{i=1}^{p} \alpha_1 \Delta CO_{2_{t-1}} + \sum_{i=1}^{q} \alpha_2 \Delta POPG_{t-1} + \sum_{i=1}^{q} a_3 \Delta URB_{t-1} + \sum_{i=1}^{q} a_4 \Delta GDPPC_{t-1} + \sum_{i=1}^{q} a_5 \Delta ENEC_{t-1} + \lambda_1 CO_{2_{t-1}} + \lambda_2 POPG_{t-1} + \lambda_3 URB_{t-1} + \lambda_4 GDPPC_{t-1}\, \lambda_5 ENEC_{t-1} + \varepsilon_{1t} \quad 3.3$$

Where:

CO_{2t} = Carbon dioxide (CO_2) emissions (measured in kilotons or metric tons per capita)
POPG = Population growth rate (annual percentage change or total population)
URB = Urbanization rate (percentage of population residing in urban areas)
GDPPC = Gross domestic product (GDP) per capita growth
ENEC = Energy consumption per capita (kg of oil equivalent)
μ_t = stochastic error terms

Where: α_0 = constant parameter to be estimated; α_1 – α_5 = short run parameters; λ_1 - λ_5 = long-run multipliers; p = optimal lag for each of the dependent variables; q = optimal lag of the independent variables; Δ = first difference operator; ε_{1t} = error terms.

4. Data Analysis

Table 4.1: Summary of Descriptive Statistics for the Variables

	CO2	GDPPC	PM2_5	POPG	URB
Mean	0.657647	1.432857	59.39516	2.572857	49.10971
Median	0.665000	1.920000	61.58000	2.640000	49.24000
Maximum	0.880000	12.21000	77.12000	2.800000	62.98000
Minimum	0.410000	-8.340000	48.14000	2.080000	35.19000
Std. Dev.	0.118221	3.934968	6.918530	0.237333	8.438041
Skewness	-0.389225	0.109973	0.124028	-1.131566	-0.014633
Kurtosis	2.572466	3.886862	2.694301	2.849447	1.780507
Jarque-Bera	1.117422	1.217562	0.200188	7.502295	2.170028
Probability	0.571946	0.544014	0.904758	0.023491	0.337897
Sum	22.36000	50.15000	1841.250	90.05000	1718.840
Sum Sq. Dev.	0.461212	526.4551	1435.982	1.915114	2420.818
Observations	34	35	31	35	35

Source: *Author's computation using E-views 12 software (2026)*

The descriptive statistics presented in Table 4.1 show that CO_2 emissions recorded a mean value of 0.657, with minimum and maximum values of 0.410 and 0.880, respectively. GDP per capita growth (GDPPC) averaged 1.432%, ranging from −8.340% to 12.210%, indicating considerable variation in economic performance during the study period. PM2.5 recorded a mean value of 59.395, with values ranging from 48.140 to 77.120. Population growth (POPG) had a mean of 2.572%, with minimum and maximum values of 2.089% and 2.800%, respectively, while urbanization (URB) averaged 49.109%, ranging from 35.190% to 62.980%. The standard deviations indicate the extent of dispersion of each variable around its respective mean, with higher values reflecting greater variability. The Jarque–Bera probability values greater than 0.05 indicate that the null hypothesis of normality cannot be rejected at the 5% significance level. Thus, the variables do not exhibit statistically significant departures from normality.

Table 4.3 KPSS Unit Root Test

Variables	KPSS at Level	Critical value 5%	KPSS at 1st Diff.	Critical value 5%	Order of Integration
CO2	0.119390	0.463000	NA	NA	1(0)

GDPPC	0.156907	0.463000	NA	NA	1(0)
PM2_5	0.322512	0.463000	NA	NA	1(0)
POPG	0.390428	0.463000	NA	NA	1(0)
URB	0.699101	0.463000	0.169709	0.463000	1(1)

Source: Researcher's computation using Eviews 12, (2026).

The results of the KPSS unit root test presented in Table 4.3 indicate that all variables are stationary at level, except the urbanization rate (URB). Specifically, the KPSS statistic for URB is 0.699101, which exceeds the 5% critical value of 0.463000. Since the KPSS test has stationarity as its null hypothesis, this result leads to the rejection of the null hypothesis, indicating that URB is non-stationary at level. However, after first differencing, the KPSS statistic falls below the 5% critical value, indicating that the differenced URB series is stationary. Thus, URB is integrated of order one, I(1), while the remaining variables are integrated of order zero, I(0). The results therefore confirm that the variables are a mixture of I(0) and I(1), which is an important consideration for subsequent econometric modelling.

The KPSS test is employed because, unlike conventional unit-root tests whose null hypothesis is non-stationarity, it takes stationarity as the null hypothesis and therefore provides complementary evidence on the time-series properties of the variables. The test was originally proposed by Kwiatkowski et al. (1992).

Table 4.3: Bounds Cointegration Tests Results for the Models

	F-STATISTICS	K	Critical value Lower bound 5%	Critical value Upper bound 5%
CO2	11.74627	4	2.56	3.49

Source: Researcher's computation using Eviews 12, (2026).

Note: K denotes number of explanatory variables

The results of the ARDL bounds test presented in Table 4.3 provide evidence of a long-run relationship among the variables. The calculated F-statistic of 11.74627 is greater than the upper-bound critical value at the 5% significance level. Therefore, the null hypothesis of no long-run relationship is rejected, confirming the existence of cointegration among the variables.

Model Results

Table 4.4: ARDL short and long run results for CO2 Emission

Dependent Variable: CO_2

Short run results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(POPG)	-0.525213	0.256374	-2.048618	0.0612
D(POPG(-1))	0.679645	0.393932	1.725286	0.1082
D(POPG(-2))	1.115412	0.302205	3.690913	0.0027
D(URB)	3.650412	0.712116	5.126150	0.0002
D(URB(-1))	-3.963646	1.194115	-3.319316	0.0055
D(URB(-2))	2.450076	0.709727	3.452138	0.0043
D(GDPPC)	-0.008193	0.002154	-3.803501	0.0022
D(GDPPC(-1))	0.006397	0.002661	2.404098	0.0318
D(GDPPC(-2))	0.009348	0.001980	4.720147	0.0004
D(ENEC)	0.003293	0.000329	10.00081	0.0000

D(ENEC(-1))	-0.001041	0.000322	-3.230323	0.0066
D(ENEC(-2))	-0.001499	0.000307	-4.890078	0.0003
CointEq(-1)*	-0.649972	0.065797	-9.878481	0.0000

Long run results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
POPG	0.014835	0.215855	0.068729	0.9463
URB	-0.011320	0.005833	-1.940600	0.0743
GDPPC	-0.044155	0.012114	-3.645043	0.0030
ENEC	0.004050	0.001377	2.940598	0.0115
C	-2.625828	1.226468	-2.140967	0.0518

R-squared 0.925174; Adjusted R-squared 0.875290

Source: Researcher's computation using Eviews 12, (2026).

The ARDL results presented in Table 4.4 reveal both short-run dynamics and long-run relationships between CO_2 emissions and the explanatory variables in Nigeria. In the short run, population growth (POPG) has a negative but statistically insignificant immediate year effect on CO_2 emissions. Its lagged coefficients are positive, although statistical significance is observed only at lag two, where a one-unit increase in population growth is associated with a 1.115-unit increase in CO_2 emissions. In the long run, population growth has a positive but statistically insignificant coefficient of 0.014, suggesting that its long-run effect on CO_2 emissions is not statistically distinguishable from zero. The positive association is consistent with the general population–environment mechanism underlying the IPAT framework.

Urbanization (URB) exhibits significant short-run effects on CO_2 emissions. The immediate year and second-lag coefficients are positive, with coefficients of 3.650 and 2.450, respectively, while the first lag is negative and statistically significant. In the long run, urbanization has a negative but statistically insignificant coefficient of −0.011.

GDP per capita growth has a negative and statistically significant immediate year effect on CO_2 emissions, while its first and second lags have positive and statistically significant coefficients of 0.006 and 0.009, respectively. In the long run, GDP per capita growth has a negative and statistically significant coefficient of −0.044, indicating that an increase in GDP per capita growth is associated with a reduction in CO_2 emissions in the long run, holding other factors constant. This finding differs from the conventional expectation that higher affluence necessarily increases environmental pressure and from some previous empirical findings. Energy consumption per capita has a positive and statistically significant immediate year effect on CO_2 emissions, with a coefficient of 0.003, while its first and second lags are negative and statistically significant. In the long run, energy consumption per capita has a positive and statistically significant coefficient of 0.0004, indicating that higher energy consumption is associated with higher CO_2 emissions, ceteris paribus. This finding is consistent with the environmental-impact mechanism underlying the IPAT framework.

The error-correction term, CointEq(−1), is negative and statistically significant, with a coefficient of −0.649972 and a p-value of 0.0000. This confirms the existence of a stable adjustment mechanism toward long-run equilibrium. Approximately 65% of the disequilibrium arising from a short-run shock is corrected within one period, indicating a relatively rapid adjustment process.

Finally, the model records an (R^2) of 0.925174, indicating that approximately 92.5% of the variation in CO_2 emissions in the estimated sample is accounted for by the regressors and dynamic terms included in the model. The adjusted (R^2) of 0.875290 indicates that the model

retains a high proportion of explained variation after accounting for the number of regressors and degrees of freedom.

Table 4.5: Post-Estimation Tests Results

Test	Null Hypothesis	F-Statistic	Probability	Decision
Serial Correlation LM Test	**H_0:** No serial correlation	0.026295	0.9741	Retain H_0
Heteroskedasticity Test	**H_0:** Homoscedasticity	1.716117	0.1522	Retain H_0
Normality Test	**H_0:** Normally distributed	0.374736	0.829138	Retain H_0

Source: *Researcher's Computation using Eviews 12, 2026.*

The post-estimation diagnostic results presented in Table 4.5 indicate that the estimated ARDL model does not exhibit evidence of the major residual problems examined. The Breusch–Godfrey LM test reports a probability value of 0.9741, which is greater than the 5% significance level. Therefore, the null hypothesis of no serial correlation cannot be rejected, suggesting that the residuals do not exhibit statistically significant serial correlation.

Similarly, the Breusch–Pagan–Godfrey heteroskedasticity test produces a probability value of 0.1522, which exceeds 0.05. Thus, the null hypothesis of homoskedasticity cannot be rejected, indicating no statistically significant evidence of heteroskedasticity in the residuals.

The Jarque–Bera test reports a statistic of 0.374736 with a probability value of 0.829138. Since the probability value exceeds 0.05, the null hypothesis of normally distributed residuals cannot be rejected. Hence, there is no statistically significant evidence that the residuals depart from normality. Overall, the diagnostic results provide no evidence of residual serial correlation, heteroskedasticity, or non-normality at the 5% significance level. These findings support the adequacy of the estimated ARDL model with respect to the specific diagnostic conditions tested and provide greater confidence in the reliability of the estimated results.

5. Conclusion and Recommendations

Conclusion

This study concludes that energy consumption is a major driver of CO_2 emissions in Nigeria, given its positive and statistically significant long-run effect. Urbanization also generates significant short-run emission pressures, while population growth has no statistically significant long-run effect. Conversely, GDP per capita growth is negatively and significantly associated with CO_2 emissions in the long run. The findings therefore suggest that Nigeria's emissions-reduction efforts should prioritize clean energy transition, energy efficiency, and sustainable urban development. The significant error-correction term further confirms a stable long-run relationship, with approximately 65% of short-run disequilibrium corrected within one period.

Recommendations

Based on the findings and conclusion drawn from this study, the following recommendations are made:

i. The Nigerian government should reduce dependence on carbon-intensive energy sources by expanding renewable energy, improving electricity efficiency, and promoting cleaner technologies.

ii. The government should integrate low-carbon transport, energy-efficient buildings, improved waste management, and compact urban planning into urban development policies.

iii. There is need to encourage investment in energy-efficient industries, cleaner production

technologies, and green infrastructure so that economic expansion does not translate into higher emissions.

iv. Environmental policies should be sustained and coordinated across energy, transport, industrial, and urban sectors. Particular emphasis should be placed on managing the environmental consequences of rising energy demand and urban expansion.

References

Ahmad, T., Bhatti, M., Urooj, K., & Javed, H. (2022). *Urban population growth, per capita energy use, and co2 emissions: Evidence from the world's fifth-most populous country.* https://doi.org/10.52131/jee.2022.0302.0029

Akinlo, A. E. (2009). The impacts of anthropogenic factors on the environment in Nigeria. *Journal of Environmental Management, 90*(3), 1422–1426. https://doi.org/10.1016/j.jenvman.2008.08.009

Ali, H. S., Nathaniel, S. P., Uzuner, G., Bekun, F. V., & Sarkodie, S. A. (2020). Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: Fresh insights from Maki cointegration and causality tests. *Heliyon, 6*(2), e03400. https://doi.org/10.1016/j.heliyon.2020.e03400

Aninwagu, V. O., & Nyeche, E. (2025). *Impact of renewable energy consumption, forest area, and economic growth on CO_2 emissions in Nigeria*. http://dx.doi.org/10.2139/ssrn.5358945

Aninwagu, V. O., Momodu, A. A., & Momodu, M. (2026). Determinants of economic growth in Nigeria. *journal of economics and allied research*, *11*(1), 588–601. https://doi.org/10.5281/zenodo.19520052

Aninwagu, V. O., Onyema, J. I., Momodu, A. A., & Amadi, C. R. (2024). Gender inequality and socioeconomic development: An analysis of the effect on poverty in Nigeria. *International Journal of Economic Research and Development Studies (JERDS), 1*(1). https://ssrn.com/abstract=5358929

Aninwagu, V. O., & Momodu, A. A. (2025). Healthcare resources and employment structure on female labor force participation in Nigeria. *International Journal of Research Publication and Reviews*, 6(6), 11406-11415. https://doi.org/10.55248/gengpi.6.0625.2357

Chew, J. M., Yap, C. K., Kumar, K. K., Cheng, W. H., Syazwan, W. M., Nulit, R., Azrizal Wahid, N., Mustafa, M., Okamura, H., Horie, Y., Yap, C. W., Aguol, K. A., & Ong, M. C. (2024). *Exploring the relationship between GDP, carbon dioxide emissions, energy consumption, population, and renewable energy production using Canada as a model country*. https://doi.org/10.37256/epr.4220244730

Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO_2 emissions. *Proceedings of the National Academy of Sciences, 94*(1), 175–179. https://doi.org/10.1073/pnas.94.1.175

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science, 171*(3977), 1212 1217. https://doi.org/10.1126/science.171.3977.1212.

Elliott, G., Rothenberg, T. J., & Stock, J. H. (1996). Efficient tests for an autoregressive unit Root. *Econometrica*, 64(4), 813–836

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353–377. https://doi.org/10.2307/2118443

Jebli, B. M., & Chaouali, I. (2025). The influence of renewable energy integration and service value-added on carbon dioxide emissions in China. *Environmental Progress & Sustainable Energy, 44.*

Momodu, A. A., Isukul, A., & Aninwagu, V. O. (2023). *Government spending, trend causes and consequences in Nigeria. https://www.economicdeskjournals.net/paper/government- spending-trend-causes-and-consequences-in-nigeria*

Ngong, C. A., Bih, D., Onyejiaku, C., & Onwumere, J. (2022). *Urbanization and carbon dioxide(CO2) emission nexus in the CEMAC countries.* https://doi.org/10.1108/meq-04-2021-0070

Nwikina, C. G., Amadi, C. R., & Nwankwor, N. U. (2024). *Population and economic development: evidence from Nigeria*. https://doi.org/10.5281/zenodo.13891225

Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development*. International Labour Office.

Pesaran, M. H., & Pesaran, B. (1997). *Microfit econometric software manual*. Oxford University Press.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approach. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

Rafindadi, A. A. (2016). Does the need for economic growth influence energy consumption and CO_2 emissions in Nigeria? Evidence from the innovation accounting test. *Renewable and Sustainable Energy Reviews, 62*, 1209–1225. https://doi.org/10.1016/j.rser.2016.05.028

Rehman, A., Ma, H., Ahmad, M., Irfan, M., Traoré, O. Z., & Chandio, A. A. (2021). *Towards environmental Sustainability: Devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan.* https://doi.org/10.1016/J.ECOLIND.2021.107460

Sane, M., Hájek, M., Phiri, J., Babangida, J. S., & Nwaogu, C. (2022). *Application of decoupling approach to evaluate electricity consumption, agriculture, GDP, crude oil production, and CO2 emission nexus in support of economic instrument in Nigeria*. https://doi.org/10.3390/su14063226

Shaheen, W., Kazim, M., Shafi, N., & Perveen, N. (2025). *Impact of population growth on CO_2 emissions in export-driven global transport: A 30-country analysis (2011-2020).* https://doi.org/10.61363/xn4kvy73

Shaheen, W., Kazim, M., Shafi, N., & Perveen, N. (2025). *Impact of population growth on CO_2 emissions in export-driven global transport: A 30-country analysis (2011-2020).* https://doi.org/10.61363/xn4kvy73

United Nations Development Programme (UNDP). (2025a). *Human Development Report 2025: A matter of choice—People and possibilities in the age of AI*. New York: UNDP.

United Nations Development Programme (UNDP). (2025b). *Human Development Report 2025: Human Development Index trends, 1990–2023*. New York: UNDP.

Wang, W., Liu, L., Liao, H., & Wei, Y. (2021). Impacts of urbanization on carbon emissions: An empirical analysis from OECD countries. *Energy Policy, 151.* https://doi.org/10.1016/j.enpol.2021.112171

World Bank. (2026a). *Population, total—Nigeria*. World Development Indicators.

World Bank. (2026b). *Urban population (% of total population)—Nigeria*. World Development Indicators.

World Bank. (2026c). *GDP per capita growth (annual %)—Nigeria*. World Development Indicators.

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics, 46*(3), 351-365. https://doi.org/10.1016/S0921-8009(03)00188-5

Yusuf, F. A., & Afroz, R. (2020). The relationship between urbanization, CO2 emissions, economic growth and energy consumption in Nigeria. *International Journal of Energy Economics and Policy, 10*(6), 491–501.

Zheng, S., Wang, R., Mak, T., Hsu, S., & Tsang, D. C. W. (2020). *How energy service companies moderate the impact of industrialization and urbanization on carbon emissions in China?* https://doi.org/10.1016/j.scitotenv.2020.141610