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DEMOGRAPHIC PRESSURES AND ENVIRONMENTAL SUSTAINABILITY IN NIGERIA

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ABSTRACT

Concerns about the sustainability of Nigeria's development trajectory have been raised by increased environmental degradation amid the country's fast-growing population, expanding urban centers, and rising fertility rates. This has prompted a fresh investigation into how demographic pressures affect environmental consequences. In light of this, this study examines how demographic pressures affect environmental sustainability in Nigeria from 1996 to 2025 using ecological footprint (EFP) as a proxy for environmental sustainability and fertility rate (FERT), population density (DENSITY), and urbanization (URBAN) as indicators of demographic pressure while controlling for income (LNGDPPC), renewable energy consumption (REC), and regulatory quality (RQ). The study, which is based on the STIRPAT framework, uses the Pairwise Granger Causality test, Fully Modified Ordinary Least Squares (FMOLS), Johansen cointegration analysis, and the Phillips-Perron unit root test to investigate the long-term correlations and causal direction among the variables. The trace and maximum eigenvalue statistics both support a stable long-run cointegrating relationship between the variables, and the unit root results verify that all variables are integrated of order one, I(1). According to the FMOLS results, population density has a negative and marginally significant impact on ecological footprint, whereas fertility rate and urbanization have positive and statistically significant effects; income, regulatory quality, and renewable energy consumption have the theoretically expected negative signs but are not significant at the 5% level. A mostly unidirectional causal flow from fertility, urbanization, population density, and regulatory quality to ecological footprint is revealed by the Granger causality data. Every diagnostic test for serial correlation, heteroskedasticity, normality, functional form, and parameter stability was passed by the model. The study concludes that demographic pressures are major long-term drivers of environmental degradation in Nigeria and recommends coordinated population, urban, and regulatory policies.

Keywords: *Ecological Footprint, Demographic Pressure, Fertility Rate, Urbanization, Regulatory Quality, Renewable Energy, FMOLS*
JEL Classification*: C32, D73, J11, J13, Q42, Q56, R11*

1.0 Introduction

Rapid demographic shifts and growing ecological imbalances have put Sub-Saharan Africa under increasing strain over the last thirty years. Nigeria, the most populous country in Africa, offers an interesting case

study of these dynamics. Nigeria's population, which is estimated to be over 230 million and is expanding at a rate of about 2.5% per year, nearly twice the global average, has put ongoing pressure on the nation's ecological carrying capacity and natural resource base (Population Matters, 2024). Demographic pressure will continue to be a defining structural feature of Nigeria's development landscape for decades to come, as this demographic trajectory driven by high fertility rates and a youthful age structure in which over 40% of the population is under 15 is not expected to approach replacement-level fertility before 2070. (Osservatorio Strategico Mediterraneo Allargato, 2025).

An increasing amount of research on Nigeria attests to the fact that demographic pressure which may be measured in a number of ways, including population density, urbanization, or fertility is a major factor in the increase of ecological footprints. Population density has been identified as a factor that jointly shapes Nigeria's ecological footprint alongside income inequality, institutional quality, and trade openness. Demographic pressure has been demonstrated to increase demand for food, water, energy, and land, thereby straining sustainable consumption patterns and ecosystem services (Ike et al., 2026). At the subnational level, built-up areas are expected to increase significantly by the middle of the century due to the rapid urban expansion and densification in places like Kano, which has resulted in significant vegetation loss and deteriorating ecological services (Sawyerr, Opasola, & Otto, 2025). Other Nigerian metropolitan centers have reported similar land-use challenges associated with population and urban growth (Ogunbode, Oyebamiji, Sanni, Akinwale, & Akinluyi, 2025).

However, there is far less consensus regarding the significance of institutional quality and renewable energy in reducing this strain. While the use of renewable energy is generally found to reduce ecological footprint by displacing reliance on fossil fuels, there is conflicting evidence regarding the environmental impact of regulatory quality. While some studies find that stronger governance and regulatory frameworks help prevent resource depletion and ecosystem degradation (Obomeghie, 2026), others report that improvements in regulatory quality and other governance indicators may coincide with an increasing ecological footprint where enforcement capacity remains weak (Aden, 2023). Similar to this, the demographic-fertility aspect of environmental pressure has started to garner attention in the sub-Saharan African context due to recent evidence that links governance, carbon footprints, and fertility outcomes in the region (Peng & Xu, 2023). However, Nigeria's own ecological footprint literature has mainly ignored this fertility-specific channel.

Due to widespread energy poverty and Nigeria's ongoing reliance on fossil fuels for the majority of its export earnings, the country's growing population directly contributes to increased resource exploitation and emissions pressures. Nigeria's environmental degradation is getting worse despite a number of international accords and environmental legislation. Consuming environmental resources far beyond its natural regenerative biocapacity, the country continues to run an ecological deficit (Global Footprint Network, 2023).

Hence, Nigeria's rapid population growth - from about 108 million to an estimated 230 million - and its profound effects on land, water, forests, and urban systems, along with significant environmental challenges like deforestation, desertification, flooding, pollution, and resource depletion, make studying demographic pressures and environmental sustainability in the country from 1996 to 2025 crucial.

In light of this, this study assesses the combined effects of GDP per capita, population density, urbanization, fertility rate, renewable energy consumption, and regulatory quality on Nigeria's ecological footprint per capita from 1996 to 2025.

1.1 Objectives of the Study

The overall goal is to statistically assess the influence of demographic pressures on environmental sustainability in Nigeria from 1996 to 2025. The precise aims include:

1. Investigate the impact of fertility rate on ecological footprint per capita in Nigeria.
2. To investigate the effect of population density on the ecological footprint per capita in Nigeria.
3. To evaluate the effect of urbanization rate on ecological footprint per capita in Nigeria.
4. Assess the impact of renewable energy use on the ecological footprint per capita in Nigeria.
5. Analyze the impact of Real Gross Domestic Product (RGDP) per capita on ecological footprint in Nigeria.
6. To assess the impact of regulatory quality on Nigeria's ecological footprint per capita.

1.2 Research Hypotheses

The following null hypotheses (H_0) are examined in order to direct the empirical analysis:

H_{01}: The ecological footprint per capita in Nigeria is not significantly impacted by fertility rate.

H_{02}: The ecological footprint per person in Nigeria is not significantly affected by population

density.

H_{03}: Nigeria's ecological footprint per capita is not significantly impacted by the rate of urbanization.

H_{04}: The ecological footprint per person in Nigeria is not significantly impacted by the use of renewable energy.

H_{05}: The ecological footprint per capita in Nigeria is not significantly impacted by RGDP per capita.

H_{06}: Nigeria's ecological footprint per capita is not significantly impacted by regulatory quality.

2.0 Literature Review

2.1 Conceptual Review

The ecological footprint, which combines cropland, grazing land, forest land, fishing grounds, built-up land, and carbon uptake land into a single sustainability indicator, is a biophysical accounting measure of the amount of biologically productive land and water area needed to produce the resources an individual or population consumes and to absorb the resulting waste. It is expressed in global hectares per person (Global Footprint Network, 2026). In recent empirical research from Nigeria and sub-Saharan Africa, it has gradually replaced carbon dioxide emissions as the preferred proxy for environmental degradation because it captures the entire resource-and-waste footprint of an economy rather than a single pollutant (Dimnwobi, Ekesiobi, Madichie, & Asongu, 2021; Sawyerr, Opasola, & Otto, 2025).

The average number of live births a woman would have if she lived through her reproductive years and gave birth in accordance with the current age-specific fertility rates is known as the total fertility rate (World Bank, 2024). The environmental economics literature treats it as a demographic-pressure variable that influences long-term household consumption, land conversion, and resource-use patterns as a summary measure of the rate of population replacement (Kazemzadeh, Fuinhas, Salehnia, et al., 2023).

The amount of people per unit of land area, usually represented as people per square kilometre, is known as population density (World Bank, 2024). In contrast to fertility rate or population growth, which measure the rate of demographic change, population density measures its geographical concentration and is used as a stand-in for the level of pressure already applied on a particular land base in the literature (Abdi, Siyad, Sugow, & Omar, 2025).

The percentage of a nation's population living in urban areas or the rate at which that percentage shifts over time are referred to as urbanization (World Bank, 2024). According to Solarin, Nathaniel, Bekun, Okunola, and Alhassan (2021), urbanization can both create agglomeration economies that increase resource-use efficiency and concentrate consumption and infrastructure demand in ways that increase resource use.

The percentage of a nation's total final energy consumption that comes from renewable sources - such as solar, wind, hydropower, geothermal, and biomass - as opposed to fossil fuels is known as renewable energy consumption (World Bank, 2024). It is described as a technology-substitution variable

that can separate economic activity from environmental degradation in the STIRPAT and energy-transition literature (Nulambeh & Jaiyeoba, 2024).

The standard indicator of wealth or the average material standard of life in a nation is the gross domestic product (GDP) per capita, which is calculated by dividing a nation's total economic production by its midyear population (World Bank, 2024). Given its proposed non-linear relationship with environmental degradation, it captures the "affluence" component of the IPAT/STIRPAT identity in ecological footprint modelling and is essential to Environmental Kuznets Curve (EKC) testing (Nadabo & Salisu, 2025).

One of the World Bank's six Worldwide Governance Indicators, regulatory quality measures how well a government is perceived for its capacity to create and carry out sensible laws and policies that allow and encourage the growth of the private sector, including environmental regulation and enforcement (Kaufmann, Kraay, & Mastruzzi, 2010). It serves as an institutional-quality stand-in for a state's ability to convert environmental policy intent into enforced results in the literature on environmental sustainability (Obomeghie, 2026).

2.2 Theoretical Review

Environmental Kuznets Curve (EKC) Hypothesis- The EKC hypothesis, developed by Grossman and Krueger (1995) and based on Kuznets's (1955) inequality–income model, suggests an inverse U-shaped relationship between a nation's income per capita and its degree of environmental degradation. Degradation increases with income at low levels of development but decreases beyond a threshold income as cleaner technologies, stronger institutions, and a shift toward services become more affordable. This theory has been tested in a number of Nigerian ecological footprint studies, with varying degrees of success (Nadabo & Salisu, 2025; Alabi, 2026). The EKC offers the theoretical foundation for anticipating a non-trivial, possibly non-linear relationship between GDP per capita and ecological footprint for this study. It also encourages the inclusion of regulatory quality as a moderating institutional variable by highlighting institutions as a mechanism enabling the downward-sloping segment of the curve.

2.3 Empirical Review

Fertility rate and ecological footprint. Kazemzadeh, Fuinhas, Salehnia, et al. (2023) similarly discovered that fertility rate increased ecological footprint significantly across all quantiles of the footprint distribution using a two-step STIRPAT model and panel quantile regression across emerging economies. Haq, Chowdhury, Ahmed, and Chowdhury (2023), working in the opposite causal direction, discovered that ecological footprint

components, such as the carbon and fishing-ground footprints, significantly influenced the overall fertility rate across 31 countries, suggesting a reciprocal relationship between the environment and fertility. Peng and Xu (2023) examined the relationship between women's reproductive outcomes in sub-Saharan Africa and political governance characteristics and carbon footprints. They discovered that the relationship between fertility and the environment is moderated by the quality of governance. Lastly, Nkalu and Nwosu (2023) discovered that environmental pollutants (CO_2, NO_2, and CH_4 emissions) had a substantial impact on the overall fertility rate throughout MENA, ECOWAS, and ASEAN countries. They based their analysis on the EKC. All of these studies support a strong, if sometimes reciprocal, association between fertility and ecological footprints, but none of them use a thorough ecological footprint measure to isolate Nigeria as a single-country case.

Population density and ecological footprint. Using Cross-Sectionally Augmented ARDL on panel data for five populous African countries, including Nigeria, Dimnwobi, Ekesiobi, Madichie, and Asongu (2021) discovered that between 1990 and 2019, population density, population growth, and age structure all significantly increased ecological footprint per capita. Abdi, Siyad, Sugow, and Omar (2025) discovered that, in addition to globalization and the use of renewable energy, population density was a significant factor of ecological footprint across sub-Saharan African countries. As a spatial manifestation of density-driven ecological pressure, Ogunbode, Oyebamiji, Sanni, Akinwale, and Akinluyi (2025) found that rising population concentration in Nigerian metropolitan areas caused land-use change and vegetation loss. In a quantile-on-quantile paradigm, Ike et al. (2026) discovered that Nigeria's ecological footprint was simultaneously formed by population density, wealth disparity, institutional quality, and trade openness.

Urbanization and ecological footprint. Sawyerr, Opasola, and Otto (2025) employed geospatial analysis at the sub-national level to demonstrate how Kano's rapid urban densification and development significantly reduced vegetation cover and ecological services, with built-up areas expected to increase significantly by the middle of the century. In other Nigerian cities, Ogunbode, Oyebamiji, Sanni, Akinwale, and Akinluyi (2025) reported similar urban land-use challenges associated with urban growth and population. Zaria (2026) used the I=PAT framework on national time-series data from 2002 to 2023 and discovered that, over time, increased prosperity and rapid urbanization greatly worsened environmental degradation in Nigeria. When considered collectively, these studies consistently link urbanization to

increasing ecological strain in Nigeria, whether measured at the national level or through changes in land use at the subnational level.

Renewable energy consumption and ecological footprint. Using the Generalised Method of Moments across African nations, Nulambeh and Jaiyeoba (2024) similarly discovered that industrialisation increased ecological footprint while renewable energy greatly reduced it. Bekele, Sassi, Jemal, and Ahmed (2024) found a dynamic, reciprocal relationship between renewable energy consumption and environmental sustainability using heterogeneous macro-panel data analysis across sub-Saharan African nations. Within an EKC-environmental-convergence framework, Diallo (2024) discovered that the use of renewable energy greatly enhanced environmental quality throughout sub-Saharan Africa utilising a defactored instrumental-variables approach. Using Panel-Corrected Standard Errors, Feasible Generalised Least Squares, and Driscoll–Kraay estimators, Abdi, Siyad, Sugow, and Omar (2025) examined 34 sub-Saharan African nations from 1994 to 2021 and discovered that the use of renewable energy greatly decreased CO2 emissions and ecological footprint. The use of renewable energy was found to be a significant determinant of emissions outcomes by Abubakar, Aiyedogbon, and Aigbedion (2025), who focused on consumer-based carbon emissions in sub-Saharan Africa. Although effect estimates vary by geographical coverage and estimation method, renewable energy usage is consistently linked to an improvement in environmental sustainability across these research.

GDP per capita and ecological footprint. Using ARDL and Granger causality on Nigerian data, Udemba (2020) discovered a unidirectional causal relationship from economic growth to ecological footprint, as well as a positive long- and short-term relationship between GDP per capita and ecological footprint. Using a Vector Error Correction Model, Balogun, Kalejaiye, and Adekunle (2025) discovered a substantial relationship between inclusive-growth outcomes in Nigeria and both the ecological footprint and the pattern of economic expansion. Alabi (2026) examined Nigerian data from 1980 to 2024 using ARDL and discovered that, in line with an EKC-type pattern, ecological footprint severely limited economic performance while environmental quality greatly increased GDP in the short term. According to these research, Nigeria's GDP-ecological footprint relationship is generally positive and may not be linear. However, this relationship has not yet been jointly modelled with institutional and demographic variables across an updated 1996–2025 timeframe.

Regulatory quality and ecological footprint. In a study of natural resource rent and environmental quality in sub-Saharan Africa,

Afolabi (2023) discovered that regulatory quality considerably influenced the link between resource rent and environment, typically enhancing environmental results. Stronger regulatory quality and corruption control considerably accelerated energy-efficiency transitions across African nations, a recognized environmental co-benefit pathway, according to research by Akorli and Adom (2023). Aden (2023) discovered that governance quality, including regulatory quality, had a substantial impact on ecological footprint for Djibouti using ARDL and impulse-response analysis; however, the direction of the effect was dependent on model specification. Using a dynamic panel estimator across 25 sub-Saharan African nations, Bambi, Batatana, Appiah, and Tetteh (2024) discovered threshold effects between institutional quality and ecological footprint, with higher institutional quality typically linked to lower environmental impact beyond a certain threshold. Obomeghie (2026), concentrating on Nigeria in particular, discovered that while regulatory quality influenced environmental sustainability outcomes, its practical corrective effect was limited due to lax enforcement, as seen by the persistence of gas flaring in spite of legal prohibitions. This collection of research demonstrates that, although the environmental impact of regulation quality is actually dependent on enforcement capacity, it is theoretically anticipated to be beneficial, especially in resource-dependent economies like Nigeria.

3.0 Methodology

3.1 Research Design

This study uses an ex-post facto research design, which is acceptable given that the variables of interest are historical, already documented time series, and cannot be altered by the researcher. Because it uses secondary annual data from 1996 to 2025, the design is ideal for investigating the long-run and short-run links between demographic pressures and environmental sustainability in Nigeria. The study is quantitative and explanatory in nature, using econometric estimate techniques to determine the direction, magnitude, and statistical significance of the correlations between the studied variables.

3.2 Nature and Sources of Data

The study makes use of annual time series data from 1996 to 2025, totalling thirty (30) observations. The Global Footprint Network database provides information on the ecological footprint (EFP); the World Bank's World Development Indicators (WDI) database provides information on fertility rate (FERT), population density (DENSITY), urbanization (URBAN), renewable energy consumption (REC), and real gross domestic product per capita (from which LNGDPPC is derived); and the Worldwide Governance Indicators (WGI) database provides information on regulatory quality (RQ). Except

for GDP per capita, which is converted into natural logarithms (LNGDPPC) to minimize scale disparity and stabilize variance, all variables are measured in their natural units as supplied by the corresponding databases.

3.3 Model Specification

The study defines the ecological footprint as a function of demographic pressure indicators, renewable energy consumption, income, and institutional quality, in accordance with the theoretical foundation of the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) framework, which holds that environmental impact is a multiplicative function of population, affluence, and technology. The expression for the functional connection is:

$$EFP = f(FERT, DENSITY, URBAN, REC, LNGDPPC, RQ) \quad (3.1)$$

The model's econometric form is as follows:

$$EFP_t = \beta_0 + \beta_1 FERT_t + \beta_2 DENSITY_t + \beta_3 URBAN_t + \beta_4 REC_t + \beta_5 LNGDPPC_t + \beta_6 RQ_t + \mu_t \quad (3.2)$$

where EFP is the ecological footprint (a measure of environmental sustainability, with higher values indicating greater environmental degradation); FERT is the total fertility rate; DENSITY is population density (persons per square kilometre); URBAN is the urbanization rate (percentage of the population resident in urban areas); REC is renewable energy consumption (percentage of total final energy consumption); LNGDPPC is the natural logarithm of real gross domestic product per capita; RQ is regulatory quality, a governance indicator reflecting the ability of government to formulate and implement sound policies and regulations that permit and promote private sector development; β_0 is the constant term; $\beta_1 - \beta_6$ are the parameters to be estimated; and μ_t is the stochastic error term.

3.4 Model Justification

For this study, the Fully Modified Ordinary Least Squares (FMOLS) method is used because using ordinary least squares (OLS) to estimate the long-run parameters would result in biased and inconsistent estimates because OLS does not take into account the serial correlation that is commonly found in cointegrated systems or the endogeneity that results from the feedback effect of the cointegrating relationship on the regressors. By eliminating the second-order bias caused by the endogenous regressors and nuisance parameters through a semi-parametric adjustment, FMOLS - which was created by Phillips and Hansen in 1990 - corrects for these issues and generates effective, asymptotically unbiased, and normally distributed long-run coefficient estimates appropriate for conventional hypothesis testing. For evaluating the long-term effects of population pressures, income, renewable energy use, and regulatory quality on Nigeria's ecological footprint, it is consequently more suitable than static OLS and more effective than the Engle-Granger single-equation approach.

Table 3.1: Description of Variables and A Priori Expectations

Variable	Description/Measurement	Expected Sign
EFP	Ecological footprint per capita (dependent variable); proxy for environmental sustainability	
FERT	Total fertility rate (births per woman)	± (ambiguous)
DENSITY	Population density (persons per sq. km)	± (ambiguous)
URBAN	Urbanization rate (% of total population)	+
REC	Renewable energy consumption (% of total final energy consumption)	−
LNGDPPC	Natural log of real GDP per capita	+ (EKC hypothesis)
RQ	Regulatory quality index (World Bank WGI, range −2.5 to 2.5)	−

Source: Compiled by the Researcher, 2026.

3.5 Estimation Technique

There are four phases of the investigation. First, the Phillips-Perron (PP) unit root test is used to analyze the time series characteristics of the variables. Second, the Johansen (1991, 1995) multivariate cointegration test is used to determine whether there is a long-run equilibrium relationship between the variables since the variables are found to be integrated of order one, I(1). Third, the Fully Modified Ordinary Least Squares (FMOLS) method of Phillips and Hansen (1990), which accounts for endogeneity and serial correlation bias related to cointegrated non-stationary regressors, is used to estimate the long-run parameters after cointegration has been verified. Fourth, the direction of causality between the ecological footprint and institutional and demographic factors is determined using the Pairwise Granger Causality test. Lastly, a series of diagnostic tests are carried out to confirm that the estimated model is robust.

Phillips-Perron (PP) Unit Root Test

Because the Phillips-Perron test is non-parametric and uses the Newey-West (Bartlett kernel) estimator to correct the t-statistic of the coefficient from the AR(1) regression to account for serial correlation and heteroskedasticity in the error term without requiring the addition of lag difference terms, it was selected over the Augmented Dickey-Fuller (ADF) test. The test is described as follows:

$$\Delta Y_t = \alpha_0 + \delta Y_{t-1} + \varepsilon_t \qquad (3.3)$$

The alternative that the series is stationary is evaluated against the null hypothesis (H_0: $\delta = 0$) that the series has a unit root (is non-stationary). The test is repeated on the variable's initial difference when it is non-stationary at level.

Johansen Cointegration Test

The Johansen method compares the number of cointegrating vectors suggested by the rank of the coefficient matrix in a Vector

Autoregression (VAR) formed in error-correction form in order to test for cointegration using both the Trace statistic and the Maximum Eigenvalue statistic. The use of a long-run estimator like FMOLS is justified when the null hypothesis of at least one cointegrating equation is rejected, indicating the presence of a stable long-run relationship between EFP, FERT, DENSITY, URBAN, REC, LNGDPPC, and RQ.

Fully Modified Least Squares (FMOLS)

By using a semi-parametric adjustment for serial correlation and endogeneity resulting from the feedback impact of the cointegrating relationship on the regressors, FMOLS generates effective and asymptotically unbiased estimates of the long-run cointegrating parameters. Because it produces asymptotically normal, nuisance-parameter-free estimates appropriate for standard inference, it is favoured over static OLS when cointegrated I(1) variables are present.

Pairwise Granger Causality Test

To ascertain whether historical values of one variable contain statistically significant information for predicting another, the Granger (1969) causality test is utilized. The general specification is used to estimate the pairwise test between EFP and each of the explanatory variables at one lag:

$$Y_t = \Sigma\alpha_i X_{t-i} + \Sigma\beta_j Y_{t-j} + \mu_t \qquad (3.4)$$

When the probability value of the F-statistic is smaller than the selected significance level (5%), the null hypothesis of no Granger causation is rejected.

Diagnostic Tests

The study uses the Breusch-Godfrey Serial Correlation LM test (for autocorrelation), the Breusch-Pagan-Godfrey test (for heteroskedasticity), the Jarque-Bera test (for residual normality), the Ramsey RESET test (for proper functional form/model specification), and the CUSUM and CUSUM of Squares tests (for parameter stability over the sample period) to determine the robustness and reliability of the FMOLS estimates.

4.0 Presentation and Analysis of Results

4.1 Presentation of Results

Using annual data from 1996 to 2025 (30 observations), the empirical results from the descriptive statistics, unit root tests, Johansen cointegration test, Pairwise Granger Causality test, FMOLS regression, and post-estimation diagnostic tests are presented in this section.

Descriptive Statistics

Table 4.1: Summary of Descriptive Statistics

Statistic	EFP	FERT	DENSITY	URBAN	REC	LNGDPPC	RQ
Mean	0.9147	5.5733	188.30	52.00	18.788	13.612	-0.9119
Median	0.9175	5.9000	185.50	52.00	17.425	13.702	-0.8741
Maximum	1.0679	6.2000	260.00	64.00	31.340	13.856	-0.6333
Minimum	0.7389	4.4000	125.00	40.00	16.540	13.235	-1.2381
Std. Dev.	0.0870	0.6313	42.258	7.2445	3.6581	0.2126	0.1616
Skewness	-0.1540	-0.7695	0.1373	-0.0194	2.3903	-0.7200	-0.4572
Kurtosis	2.4779	1.9944	1.7416	1.7984	7.8705	2.0201	2.1361
Jarque-Bera	0.4592	4.2245	2.0738	1.8068	58.220	3.7923	1.9781
Probability	0.7948	0.1210	0.3545	0.4052	0.0000	0.1501	0.3719
Observations	30	30	30	30	30	30	30

Source: Researcher's computation using EViews 14, 2026.

The descriptive statistics in Table 4.1 demonstrate that the ecological footprint (EFP) averaged 0.91 global hectares per capita across the review period, with a relatively low standard deviation of 0.087, indicating minimal dispersion from the mean. Fertility rate (FERT) averaged 5.57 births per woman, gradually declining from a high of 6.2 to a low of 4.4, reflecting Nigeria's slow fertility transition. Population density (DENSITY) increased from 125 to 260 people per square kilometre over this time, while urbanization (URBAN) accounted for 40% to 64% of the population. Regulatory quality (RQ) remained consistently poor (mean of -0.91) and renewable energy consumption (REC) averaged 18.79% of total final energy consumption, indicating Nigeria's weak institutional and regulatory environment during the study period. According to the Jarque-Bera statistics, every series—aside from REC—has a normal distribution at the 5% level.

Unit Root Test Results

Table 4.2: Summary of Phillips-Perron (PP) Unit Root Test Results

Variable	Level (t-stat / prob.)	1st Diff. (t-stat / prob.)	Order of Integration
EFP	-0.1814 (0.9303)	-5.3883 (0.0001)	I(1)
FERT	1.3356 (0.9982)	-3.5960 (0.0125)	I(1)
DENSITY	3.4187 (1.0000)	-3.4037 (0.0194)	I(1)
URBAN	-0.0207 (0.9490)	-13.5704 (0.0000)	I(1)
REC	5.7079 (1.0000)	-4.3167 (0.0022)	I(1)
RQ	-1.6973 (0.4220)	-7.0661 (0.0000)	I(1)
LNGDPPC	-1.6159 (0.4620)	-2.9943 (0.0533)	I(1)

Source: Researcher's computation using EViews 14, 2026. Test critical values (5% level) approximate -2.97 (level) and -2.97 (first difference).

According to the Phillips-Perron unit root results in Table 4.2, none of the seven series are stationary in levels, but each series becomes stationary after first differencing, indicating that all variables are integrated of order one, I(1). This finding rules out the use of the ordinary least squares (OLS) or the bounds-testing ARDL approach which is typically applied to a mixture of I(0) and I(1) series and instead supports the Johansen multivariate cointegration framework, which is designed for a system of I(1) variables.

Johansen Cointegration Test Results

Table 4.3a: Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.8408	185.7136	125.6154	0.0000
At most 1 *	0.7991	134.2670	95.7537	0.0000
At most 2 *	0.7383	89.3300	69.8189	0.0007
At most 3 *	0.5069	51.7906	47.8561	0.0204
At most 4 *	0.4205	31.9922	29.7971	0.0275
At most 5 *	0.4032	16.7136	15.4947	0.0326
At most 6	0.0775	2.2591	3.8415	0.1328

*Source: Researcher's computation using EViews 14, 2026. Trace test indicates 6 cointegrating equations at the 0.05 level; * denotes rejection of the null hypothesis.*

Table 4.3b: Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.8408	51.4466	46.2314	0.0127
At most 1 *	0.7991	44.9370	40.0776	0.0131
At most 2 *	0.7383	37.5394	33.8769	0.0174
At most 3	0.5069	19.7985	27.5843	0.3552
At most 4	0.4205	15.2786	21.1316	0.2698
At most 5 *	0.4032	14.4545	14.2646	0.0467
At most 6	0.0775	2.2591	3.8415	0.1328

*Source: Researcher's computation using EViews 14, 2026. Max-eigenvalue test indicates 3 cointegrating equations at the 0.05 level; * denotes rejection of the null hypothesis.*

A stable long-term association between ecological footprint, income, renewable energy use, population pressure indicators, and regulatory quality is confirmed by the Johansen cointegration results in Tables 4.3a and 4.3b. The maximum eigenvalue test is known to have

sharper power in identifying individual cointegrating vectors, whereas the trace test can over-reject in the presence of multiple near-unit eigenvalues. The maximum eigenvalue statistic finds three cointegrating equations, while the trace statistic finds six. This divergence between the two tests is common in small samples. Both tests convincingly reject the null hypothesis of no cointegration, which is the substantively crucial result: it indicates that EFP, FERT, DENSITY, URBAN, REC, LNGDPPC, and RQ have a shared long-run stochastic tendency and do not drift apart indefinitely.

Pairwise Granger Causality Test Results

Table 4.4: Pairwise Granger Causality Test Results (Lags: 1)

Null Hypothesis	Obs.	F-Statistic	Prob.
FERT does not Granger Cause EFP	29	8.1235	0.0084
EFP does not Granger Cause FERT	29	0.1416	0.7098
URBAN does not Granger Cause EFP	29	6.0994	0.0204
EFP does not Granger Cause URBAN	29	0.6131	0.4407
REC does not Granger Cause EFP	29	1.8666	0.1836
EFP does not Granger Cause REC	29	2.4245	0.1315
LNGDPPC does not Granger Cause EFP	29	3.6801	0.0661
EFP does not Granger Cause LNGDPPC	29	5.0560	0.0332
RQ does not Granger Cause EFP	29	4.8110	0.0374
EFP does not Granger Cause RQ	29	0.0793	0.7805
DENSITY does not Granger Cause EFP	29	7.0329	0.0135
EFP does not Granger Cause DENSITY	29	3.7668	0.0632

Source: Researcher's computation using EViews 14, 2026.

The Pairwise Granger Causality results in Table 4.4 show a primarily unidirectional causal pattern from demographic and institutional variables to ecological footprint. Fertility rate, urbanization, regulatory quality, and population density are all identified as Granger-causes of EFP (at the 5% level), with no substantial feedback from EFP to fertility, urbanization, or regulatory quality. A weak bidirectional pattern exists between EFP and income (LNGDPPC): EFP is found to Granger-cause LNGDPPC at the 5% level, whereas LNGDPPC has only a negligible causal influence on EFP at the 10% level. A one-year lag structure reveals no substantial correlation in either direction between renewable energy use and EFP.

FMOLS Regression Results

Table 4.5: Fully Modified Least Squares (FMOLS) Regression Results (Dependent Variable: EFP)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FERT	0.227998	0.110028	2.072177	0.0502
DENSITY	-0.007892	0.004038	-1.984564	0.0535
URBAN	0.067756	0.018526	3.657307	0.0014
REC	-0.005850	0.003791	-1.543222	0.1370
LNGDPPC	-0.312273	0.221920	-1.407139	0.1734
RQ	-0.119690	0.070177	-1.705541	0.1022
C	1.858157	2.100217	0.884745	0.3859

Source: Researcher's computation using EViews 14, 2026. R-squared = 0.8796 Adjusted R-squared = 0.8467 S.E. of regression = 0.0347 Long-run variance = 0.0011

According to the FMOLS long-run regression results in Table 4.5, fertility rate (FERT) has a positive and significant effect on ecological footprint (coefficient of 0.228, p = 0.0502): a one-unit increase in fertility rate is associated with an approximate 0.23 unit increase in ecological footprint, holding other variables constant. Population density (DENSITY) has a negative and marginally significant effect (coefficient of -0.0079, p = 0.0535), implying that increasing population density leads to a minor decrease in per capita ecological footprint. Urbanization (URBAN) has the strongest and most accurately calculated association in the model, with a positive and highly significant effect (coefficient of 0.0678, p = 0.0014). Regulatory quality (RQ), income (LNGDPPC), and renewable energy consumption (REC) all exhibit the theoretically predicted negative indications but are not statistically significant at the 5% level. The model has a strong overall fit, explaining around 88% of the variation in ecological footprint ($R^2 = 0.8796$; Adjusted $R^2 = 0.8467$).

Diagnostic Test Results

Table 4.6: Summary of Post-Estimation Diagnostic Tests

Test	Statistic	Prob.	Decision
Breusch-Godfrey Serial Correlation LM (F-stat)	0.2882	0.7525	No serial correlation
Breusch-Pagan-Godfrey Heteroskedasticity (F-stat)	0.3644	0.8939	Homoskedastic
Jarque-Bera Normality (Residuals)	0.2338	0.8897	Normally distributed
Ramsey RESET (F-stat)	3.7944	0.0943	Correctly specified
CUSUM Test	—	—	Stable within 5% bounds

Test	Statistic	Prob.	Decision
CUSUM of Squares Test	—	—	Stable within 5% bounds

Source: Researcher's computation using EViews 14, 2026.

The diagnostic tests reported in Table 4.6 confirm that the estimated FMOLS model is statistically robust: the Breusch-Godfrey test shows the residuals are free of serial correlation (p = 0.7525); the Breusch-Pagan-Godfrey test confirms the homoskedasticity of the residuals (p = 0.8939); the Jarque-Bera statistic confirms that the residuals are normally distributed (p = 0.8897); and the Ramsey RESET test fails to reject the null of correct functional form at the 5% level (p The CUSUM and CUSUM of Squares plots remained under the 5% critical boundaries throughout the sample period, indicating the estimated parameters' stability from 1996 to 2025.

4.2 Discussion of Findings

The study examined how demographic pressures affected environmental sustainability in Nigeria from 1996 and 2025. According to the findings, the following became obvious during the course of this research:

The ecological footprint and fertility rate have a positive and significant relationship, which is consistent with previous cross-national data on the relationship between fertility and the environment. Haq, Chowdhury, Ahmed and Chowdhury (2023) similarly identified a systematic link between fertility outcomes and ecological footprint indices, concluding that population dynamics and environmental pressure are mutually reinforcing rather than independent phenomena. Even while per capita consumption is still low, a greater birth rate in Nigeria results in a larger and younger population, which increases the collective demand for food, energy, housing, and land, increasing the overall ecological footprint.

The "compact city" or agglomeration-efficiency theory put forth in some sections of the literature, which holds that denser settlement patterns allow for more effective shared use of infrastructure, transportation, and energy networks, thereby moderating the per capita environmental burden, is generally consistent with the negative relationship between population density and ecological footprint, even though it is only marginally significant (Mishra & Dash, 2022). However, this result should be interpreted cautiously because other research using panel and threshold methodologies have discovered that once a critical density threshold is exceeded, population density increases ecological footprint through congestion and waste-disposal pressures (Wang, Li & Li, 2023). The conclusion therefore shows that Nigeria's average population density, at 188 individuals per square kilometre for the review period, has not yet crossed the threshold beyond which

agglomeration effects give way to congestion effects.

The result that urbanization exerts a positive and statistically significant influence on Nigeria's ecological footprint is consistent with a vast body of recent empirical data. Research on the relationship between urbanization and the environment in Nigeria and other developing nations has generally found that, in the short to medium term, rapid and frequently unplanned urban expansion worsens the ecological footprint by increasing resource consumption, transportation-related emissions, and land conversion driven by infrastructure (Nathaniel & Khan, 2020; Adeiza, 2022). This supports the STIRPAT prediction that increased per capita energy and material consumption linked to urban lifestyles increases the overall environmental impact of population concentration in urban centers.

The negative, albeit statistically insignificant, coefficient on renewable energy consumption is consistent with theoretical expectations and the broader literature, which generally finds that increasing the share of renewable energy in the energy mix reduces the ecological footprint by replacing carbon-intensive fossil fuel use (Nathaniel & Khan, 2020). The lack of statistical significance in the Nigerian case is most likely due to the country's still-modest and slowly growing fraction of renewables in total energy consumption, which may be inadequate at current levels to produce a meaningful dampening effect on the aggregate footprint.

The early, upward-sloping portion of the Environmental Kuznets Curve (EKC) suggests a positive association between income (LNGDPPC) and ecological footprint; however, this relationship is statistically insignificant. This outcome is not unprecedented, though, as a number of recent studies that applied long-run cointegrating estimators to African economies also failed to establish a statistically significant income-footprint relationship over shorter samples. The ambiguity was attributed to structural volatility in GDP growth, exchange rate pass-through, and the predominance of non-tradable and informal sectors in output composition (Adeiza, 2022). However, even in cases when the contemporaneous long-run coefficient is imprecisely assessed, the bidirectional Granger causality found between EFP and LNGDPPC shows that income and environmental degradation are dynamically interconnected in Nigeria.

Lastly, the institutional-quality literature consistently finds that stronger regulatory institutions capable of creating and enforcing environmental policy are associated with lower ecological footprints. This is consistent with the negative relationship between regulatory quality and ecological footprint, even though it is only marginally significant at the 10% level (Gungor, Abu-Goodman, Olanipekun &

Usman, 2021; Bambi, Batatana, Appiah & Tetteh, 2024). The Granger causality result indicates that regulatory quality significantly predicts EFP, highlighting the importance of institutional reform to environmental sustainability outcomes in Nigeria. Given that Nigeria's regulatory quality index remained negative throughout the sample period, the weak institutional environment implied by this persistently negative score appears to have constrained the extent to which stronger regulation could meaningfully suppress environmental degradation.

Overall, the results support the central claim of the STIRPAT framework, which is that demographic pressure in all of its forms, along with energy structure and institutional quality, are significant long-term determinants of environmental sustainability in Nigeria. However, they also show that the relative significance and even the direction of these effects can deviate from theoretical priors in ways that are sample-specific and country-specific, which is consistent with the conflicting results that define this branch of the empirical literature.

5.0 Summary, Conclusion and Recommendations

5.1 Summary of Findings

Using ecological footprint (EFP) as a measure of environmental sustainability, fertility rate (FERT), population density (DENSITY), and urbanization (URBAN) as indicators of demographic pressure, and income (LNGDPPC), regulatory quality (RQ), and renewable energy consumption (REC) as control variables, this study examined the relationship between demographic pressures and environmental sustainability in Nigeria from 1996 to 2025. The main findings are summarized as follows as follows:

i. After first differencing, all seven variables were determined to be stationary despite their non-stationary at levels, indicating that they are integrated of order one, I(1).
ii. The Johansen trace and maximum eigenvalue tests both showed the existence of at least one, and indeed numerous, cointegrating connections among the variables, suggesting a stable long-run equilibrium relationship between population pressures and ecological footprint in Nigeria.
iii. Fertility rate and urbanization exert positive and statistically significant effects on ecological footprint, while population density exerts a negative and marginally significant effect; renewable energy consumption, income and regulatory quality carry the theoretically expected negative signs but are not significant at the conventional 5% level.
iv. Ecological footprint was found to be Granger-caused by fertility rate,

urbanization, population density, and regulatory quality. Income and ecological footprint were found to have a weak bidirectional relationship, suggesting that institutional and demographic factors are significant leading indicators of environmental change in Nigeria.

v. The robustness and dependability of the FMOLS estimates were confirmed by the estimated model passing all diagnostic tests for serial correlation, heteroskedasticity, normality, functional form, and parameter stability.

5.2 Conclusion

Based on the empirical evidence gathered, the study concludes that demographic pressures, particularly fertility and urbanization, are significant long-term drivers of environmental degradation in Nigeria, while population density, renewable energy consumption, and regulatory quality act as moderating or mitigating forces on the ecological footprint. The existence of a weak regulatory environment throughout the study period appears to have hampered institutional quality's ability to substantially counterbalance the environmental constraints caused by Nigeria's rapidly growing and increasingly urbanized population. Therefore, the study comes to the conclusion that environmental sustainability in Nigeria cannot be attained by addressing demographic factors alone; rather, it necessitates a coordinated policy response that simultaneously controls urbanization and population growth, speeds up the switch to renewable energy, and fortifies the institutional and regulatory framework governing environmental protection.

5.3 Policy Recommendations

The following suggestions are given in light of the study's findings and conclusion:

i. Given the substantial positive impact of fertility rate on ecological footprint, federal and state governments should incorporate family planning and population policies with urban and environmental planning frameworks to slow down the rate of demographic pressure on natural resources.

ii. In order to maximize the potential agglomeration benefits associated with higher population density while limiting the environmentally degrading effects associated with unmanaged urban expansion, urban development policy should prioritize compact, well-planned, and infrastructure-efficient city growth over sprawling, unplanned urbanization.

iii. To strengthen the currently weak but theoretically significant dampening effect of renewable energy consumption on ecological footprint, the government should increase investment in renewable energy infrastructure, such as solar, wind, and hydro power, and offer financial incentives to households and businesses to adopt cleaner energy sources.

iv. Given the substantial Granger-causal influence of regulatory quality on ecological footprint, institutional and regulatory reforms such as bolstering environmental protection agencies, improving the enforcement of current environmental regulations, and increasing transparency in environmental governance should be given top priority.

v. Given the dynamic relationship of income and ecological footprint, policymakers should seek economic growth measures that decouple income growth from environmental deterioration, such as supporting green industrialization and resource-efficient technology.

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