

EFFECTS OF URBANISATION ON ENVIRONMENTAL DEGRADATION IN NIGERIA: AN ARDL BOUNDS TESTING APPROACH

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Abstract

This study examines the short-run and long-run impacts of urbanisation on environmental degradation in Nigeria from 1981 to 2024. Nigeria is undergoing rapid demographic transition with high rural to urban migration and emergence of large cities. This has led to high carbon emissions and ecological stress. However, the temporal dynamics between urbanisation and environmental outcomes in Nigeria are under-modelled; most previous studies are based on single environmental indicators and on linear modelling which may not fully model the complexity of urbanisation–environment relations. This study analyses both the short-run adjustment dynamics and long-run equilibrium relationships between urbanisation and two complementary environmental indicators, carbon dioxide emissions and ecological footprint using the Autoregressive Distributed Lag (ARDL) bounds testing framework. Results indicate that urbanisation has a significant and positive long-run impact on CO₂ emissions and ecological footprint, supporting the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) hypothesis, which states that the concentration of population and economic activities leads to a greater environmental stress. The results of the error correction model verify the cointegration and stable long-run equilibrium with a speed of adjustment of 41.8% per year for carbon emissions. Energy turns out to be a key short-term CO₂ determinant and GDP per capita exhibits EKC-like trends for ecological footprint. The results highlight the need to incorporate environmental sustainability goals into the National Urban Development Policy and the Climate Change Act 2021 as well as other urban development policies in Nigeria in order to fulfill SDG 11 and SDG 13 targets.

Keywords: Urbanisation, Environmental degradation, Carbon emissions, Ecological footprint, ARDL

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Introduction

Environmental degradation is among the most urgent sustainable development issues of the twenty-first century, a challenge that is imperiled by carbon emissions, ecological imbalance and the overuse of natural resources throughout the world, compromising climate stability, biodiversity and human wellbeing on a global scale. Sub-Saharan Africa, and Nigeria specifically, has been witnessing some of the highest rates of urbanisation in recent decades among developing economies, as rural–urban migration, population growth and changes in economic structure contribute to the clustering of people and economic activity in cities. Lagos, Abuja, Kano and Port Harcourt have experienced significant growth, leading to various economic opportunities and environmental issues such as air pollution, waste management problems, land degradation and high carbon emissions (Adeyemo & Olakanmi, 2026; Ogborogu et al., 2026).

The link between urbanisation and the environmental pressures of urbanisation has received significant empirical research, and most of the studies have found a positive correlation between urbanisation and environmental pressure, with urbanisation being associated with higher energy consumption, transport emissions, industrial production and waste generation. The dynamic temporal structure of this relationship, however, has not been adequately modelled in the Nigerian context where short-run adjustment dynamics and long-run equilibrium effects of the relationship are

not distinguished. Furthermore, there are only few studies that use several environmental proxies, usually only CO₂ emissions, and underestimate the entire range of ecological pressures related to urbanisation. A wider and more comprehensive approach can be achieved using the ecological footprint, which represents the overall ecological demands on natural systems.

The investigation is driven by several important gaps. First, although urbanisation is acknowledged as a significant environmental driver of stress in Nigeria (Nathaniel, 2020; Yusuf, 2023), the functional temporal dimension of the short-run impacts and long-run equilibrium effects have not been explicitly modelled in a systematic way using a proper ARDL technique with diagnostic validation. Second, CO₂ emissions are not a comprehensive indicator of environmental sustainability; the ecological footprint, which takes into account land use, resource consumption and ecosystem service use in addition to emissions of CO₂, offers a broader measurement of environmental sustainability. Third, previous research has neglected to account for the long-run persistence of environmental impacts and the speed of adaptation towards environmental long-run equilibrium after environmental shocks, which both play a crucial role in environmental policy design. Fourth, the effect of all the complementary macroeconomic variables (energy consumption, GDP per capita, industrialisation and trade openness) have not been thoroughly explored in a single ARDL framework in Nigeria.

The main question in this paper is: What are the short- and long-term impacts of urbanisation on environmental degradation in Nigeria? This study aims to (i) test for long-run cointegration between urbanisation and the environmental degradation indicators; (ii) estimate the short-run dynamic adjustments between environmental indicators response to changes in urbanisation; and (iii) estimate the long-run elasticities of the environmental degradation indicators with respect to urbanisation.

This paper has four original contributions to the environmental economics literature on Nigeria: (i) It uses complementary environmental indicators (CO₂ and EFP) in a unified ARDL framework, which is a more comprehensive environmental assessment; (ii) it rigorously models temporal dynamics of the urbanisation–environment relationship, distinguishing persistent short-run effects from long-run equilibrium impacts; (iii) it provides comprehensive post-estimation validation including normality, serial correlation, heteroskedasticity, ARCH effects and structural stability tests using CUSUM; and (iv) it generates policy-relevant evidence on environmental adjustment speeds, which is critical for designing time-appropriate environmental governance interventions.

Literature Review

Conceptual Review

Environmental degradation is an impairment of environmental quality due to human or anthropogenic activities that affect the natural ecosystems and the natural resources of these ecosystems. It is

usually manifested in the increase of the concentration of carbon in the atmosphere, deterioration of land, decline in biodiversity, and growing stress on ecological systems. Carbon dioxide (CO₂) emissions and the ecological footprint are the most commonly used proxies of environmental degradation in the empirical literature because CO₂ emissions reflect atmospheric pollution while ecological footprint reflects the overall demand on the biosphere (Nathaniel & Adeleye, 2021). These indicators have been embraced by several studies on Nigeria, especially with the increasing demand for their energy resources and increasing urbanisation which has exacerbated environmental stress (Yusuf, 2023).

The second important variable in this study is urbanisation, which refers to the gradual movement of population and economic activities from rural to urban areas, due to rural-urban migration, population growth and structural economic changes. Urban areas create productivity benefits and economic opportunities, but rapid urban growth increases the pressure on the environment through an increase in energy consumption, congestion and transport, waste accumulation, and land use change (Erdogan et al., 2022; Abdulqadir, 2024). Nigeria's major cities have grown significantly over the last few decades, bringing significant economic benefits as well as huge ecological liabilities (Adeyemo & Olakanmi, 2026; Ogborogu et al., 2026). The conceptual connection between urbanisation and environmental degradation is, therefore, the basis for the empirical analysis of this study.

Empirical Review

The empirical literature on the urbanisation-environmental degradation nexus is voluminous, but results are inconclusive, especially on the direction and magnitude of impacts in various country and method contexts. In Nigeria, Nathaniel (2020) applied the STIRPAT-ARDL approach to arrive at conclusions that urbanisation has a statistically significant positive short-run and long-run impact on CO₂ emissions. Likewise, Musa et al. (2021) used the modified Toda-Yamamoto causality procedure and found that urbanisation is a causal precursor of CO₂ emissions in Nigeria while bi-directional causalities were also found between urbanisation and industrialisation. However, the effects of urbanisation on biodiversity loss are not straightforward, and, according to Yusuf (2023), using an ARDL model that incorporates structural breaks, urbanisation has a negative short-term effect but a positive long-term effect. However, Shehu (2020) found negative correlation between urbanisation and CO₂ emission in Nigeria, indicating that urbanisation can help achieve resource efficiency under specific structural conditions. Focusing on a wider range of variables, such as openness to trade and natural resources, Dada et al. (2022) also concluded that the relationship between urbanisation and ecological footprint in Nigeria is not straightforward and is sensitive to the model. The differences between these results make it clear that methodological decisions (for example, the choice of environmental indicator and the consideration of dynamics) can influence the empirical results.

In addition to Nigeria, regional and cross-country studies point to the general conclusion that urbanisation causes environmental degradation in developing economies, but the impact is not uniform and depends on the specific circumstances. Erdogan et al. (2022) showed a significant positive relationship between urbanisation and emissions for a sample of African countries, which was suggested to be due to the energy systems in most of the African cities that are dominated by fossil fuels, and the lack of environmental infrastructure. This trend was corroborated by Dlamini et al. (2024) who applied a System Generalised Method of Moments approach to estimate the effects of urbanization on carbon emissions for Sub-Saharan Africa, where urban population growth was shown to have a strong effect on increasing carbon emissions both because of the increase in energy demand and industrial activity. Udoh et al. (2026) analysed the country groups of BRICS, MINT and SAARC at the macro level and found urbanisation had a significant impact on CO₂ and greenhouse gas emissions for most of these groups, consistent with the findings of the STIRPAT model. Shaheen and colleagues (2025) used the ARDL technique in conjunction with grey-modelling predictions for Pakistan and found that long-run urbanisation is found to significantly drive up the emissions of nitrous oxide, while the positive effects of economic growth and energy efficiency are partially offsetting the total accumulation of carbon for the country.

Few studies find a negative or non-existent urbanisation-environment relationship, which is usually explained by the benefits

of urban efficiency, economies of scale in service provision and technological diffusion. In a global panel, Ibrahim and Simian (2023) reported a negative urbanisation-CO₂ relationship, while Ali et al. (2017) showed that urban density is associated with better environmental outcomes in Singapore, due to the presence of mature infrastructure and robust governance which limits environmental costs. These results indicate the impact of urbanisation on the environment is mediated by the institutional and technological setting and highlight the importance of country-specific analyses taking into account the local structure.

Generally, the literature reveals three common themes: first, urbanisation has a tendency to exacerbate environmental degradation in fossil-fuel dependent economies with poor environmental governance, as suggested by Yusuf (2023); second, the short-run and long-run impacts of urbanisation on the environment may not necessarily be symmetrical, depending on the environmental indicator being used; third, the importance of the environmental indicator – whether CO₂ emissions or ecological footprint – shapes empirical results. To address these issues, the present study models two complementary indicators simultaneously in a single model under the framework of ARDL to provide a more comprehensive and internally consistent assessment compared to previous studies that were based on a single indicator.

Theoretical Review

The theoretical framework of this study is based upon three theoretical approaches that complement one another. The extended STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model, which is a stochastic version of the IPAT model, is developed by Dietz and Rosa (1994) and is used as the theoretical framework. The model separates the effects of population, affluence and technology on environmental impact, and presents them in an economic elasticity form that is suitable for econometric estimation. The urbanisation dimension can be used to represent the population dimension; the affluence dimension can be represented by GDP per capita; and the technology dimension can be represented by energy consumption and industrialisation. The STIRPAT framework directly spurs the variable selection, the log-linear specification, and the positive long-run effect of urbanisation on CO₂ emissions and ecological footprint. The application of the model to Nigeria by Nathaniel (2020) and to Sub-Saharan Africa by Abdulqadir (2024) confirms its applicability to the current situation.

A second model that complements the STIRPAT is the Environmental Kuznets Curve (EKC) hypothesis of Grossman and Krueger (1995) which states that environmental degradation peaks at some point before declining as per capita income rises. According to the theory, environmental pressure will increase in the first stages of economic development during periods of increased industrialisation and urbanisation, and then decrease as income increases, cleaner

technologies spread and environmental regulation tightens. This non-linear income-environment path is the rationale behind the use of GDP per capita as a control variable in the ARDL models and explains the interest in analysing the sign differences between the short-run and long-run income coefficients of the ARDL estimates.

There is also the theory of the Urban Environmental Transition (UET). The UET framework assumes that cities experience a series of environmental challenges, ranging from sanitation and local pollution issues in early urbanisation, to industrial emissions and energy-related pressures at intermediate stages, to global climate-scale impacts at advanced stages. This staged pathway is especially relevant for Nigeria where multiple major cities experience pollution levels typical of both early and intermediate transition stages. The UET theory then provides a context to the asymmetric short-run and long-run ARDL outcomes and underpins the findings of this study that the effect of urbanisation on the environment can vary with the indicator and over time.

Methodology

Model Specification

The model of environmental degradation is derived from the extended STIRPAT framework, which is a function of urbanisation and control variables. The general functional relationship is:

$$ENV = f(URB, ENC, GDPPC, IND, TOP) \quad (1)$$

The empirical log-linear specification for ARDL is:

$$\begin{aligned} \ln ENVD_t &= \alpha_0 + \alpha_1 \ln URB_t + \alpha_2 \ln ENC_t \\ &+ \alpha_3 \ln GDPPC_t + \alpha_4 \ln IND_t + \alpha_5 \ln TOP_t \\ &+ \varepsilon_t \end{aligned}$$

where $\ln ENVD$ is the natural logarithm of the environmental degradation indicator (CO₂ emissions or ecological footprint), $\ln URB$ is the natural logarithm of urbanisation (urban population as % of total), $\ln ENC$ is the natural logarithm of energy consumption (kg oil equivalent per capita), $\ln GDPPC$ is the natural logarithm of GDP per capita (constant USD), $\ln IND$ is the natural logarithm of industrialisation (industry value added as % of GDP), and $\ln TOP$ is the natural logarithm of trade openness (trade as % of GDP). Logarithmic transformation will lead to the decrease of heteroskedasticity and will make it possible to interpret the coefficient in the elasticity form.

Unrestricted error correction representation of the ARDL model allows for the simultaneous short and long-run estimation of the ARDL and is presented as:

$$\begin{aligned} \Delta \ln ENVD_t &= \varphi_0 + \sum_i \varphi_{1i} \Delta \ln ENVD_{t-i} \\ &+ \sum_i \varphi_{2i} \Delta \ln URB_{t-i} + \dots + \delta_1 \ln ENVD_{t-1} \\ &+ \delta_2 \ln URB_{t-1} + \delta_3 \ln ENC_{t-1} \\ &+ \delta_4 \ln GDPPC_{t-1} + \delta_5 \ln IND_{t-1} \\ &+ \delta_6 \ln TOP_{t-1} \\ &+ \mu_t \end{aligned} \quad (3)$$

Estimation Technique

An Autoregressive Distributed Lag (ARDL) bounds testing procedure, as in Pesaran, Shin and Smith (2001), is chosen for a number of reasons: (1) it is valid for variables integrated at I(0) or I(1) or a mixture of both, which is relevant in this

study with a small number of 44 years; (2) it is appropriate for small samples, which is relevant in this study, with the time series limited to 44 years; (3) it estimates both short-run dynamics and long-run equilibrium parameters in the same framework; and (4) it is robust to endogeneity since suitable lags are incorporated.

The ARDL bounds F-test is used to test the cointegration null hypothesis (H_0 : no long-run relationship). If the calculated F-statistic is greater than the upper critical value $I(1)$, then cointegration is considered present. The best lag length is determined using Akaike Information Criterion (AIC) as suggested by Pesaran et al. (2001). The error correction model (ECM) gives estimates of short-run adjustment and the error correction term (ECT) while the long-run coefficients are calculated as the ratio of level-variable coefficients to the coefficient of the lagged dependent variable.

Pre-Estimation Tests

In order to check for the absence of $I(2)$ variables, unit root pre-tests are performed with both the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. Both tests are applied in conjunction with trend and constant specifications to give strong integration evaluations. The mixed $I(0)/I(1)$ results (discussed in Section 4) support the ARDL approach. Correlation analysis is performed as preliminary diagnostic to determine bivariate relationships and test for extreme multicollinearity among explanatory variables.

Post-Estimation Tests

Model adequacy is checked using the Jarque-Bera test for normality of the residuals, the Breusch-Godfrey serial correlation LM test (with 2 lags), the Breusch-Pagan test for heteroskedasticity, the ARCH LM test for conditional heteroskedasticity, the Durbin-Watson statistic, and the CUSUM and CUSUM of Squares test for parameter stability. These diagnostics are necessary for inferring about the reliability of coefficient estimates to draw policy conclusions.

Variable Measurement and Data Sources

Annual time-series data for Nigeria cover 1981-2024 ($n = 44$). Carbon dioxide emissions (CO_2 , metric tons per capita) and ecological footprint (EFP, global hectare per capita) come from World Development Indicators (WDI) and Global Footprint Network, respectively. Energy consumption (ENC, kg oil equivalent per capita), GDP per capita (GDPPC, constant USD), industrialisation (IND, industry value added as % of GDP) and trade openness (TOP, exports plus imports as % of GDP) all come from WDI.

A-Priori Expectations

Urbanisation (URB) is believed to have a direct positive (+) impact on environmental degradation due to the greater demand for energy, transportation, industrial growth and waste production. Energy consumption (ENC) is expected to have a positive influence (+) on environmental degradation because it is through the use of fossil fuels. GDP per capita (GDPPC) has mixed expected effects ($\pm$), that is, positive at low levels of income, but negative at

higher incomes as per EKC. Industrialisation (IND) is expected to increase environmental pressure (+). Trade openness (TOP) has an ambiguous effect ($\pm$) on the basis of the trade composition and technology transfer.

Results and Discussion

Pre-Estimation Results

Descriptive statistics confirm moderate average environmental degradation: mean

CO₂ = 0.654 (SD = 0.128) and mean EFP = 0.915 (SD = 0.138) over 1981-2024. Pearson correlation reveals and confirms the preliminary evidence of positive relationship between urbanisation and CO₂ with statistically significant values ($r = 0.404$ and p value < 0.01). The results from the unit root tests (Table 1) supports mixed I(0)/I(1) integration (no variable is I(2)), which justifies the ARDL approach.

Table 1: Unit Root Test Results (ADF and PP)

Variable	PP Level	PP 1st Diff	ADF Level	ADF 1st Diff	Order
CO ₂	-3.056**	-7.837***	-3.008**	-7.850***	I(0)/I(1)
lnEFP	-9.764***	-55.765***	-0.831	-59.529***	I(0)/I(1)
lnURB	-1.185	-5.368***	-0.893	-5.368***	I(1)
lnENC	-1.930	-7.014***	-1.930	-6.780***	I(1)
lnGDPPC	-0.622	-4.235***	-0.807	-4.235***	I(1)
lnIND	-0.945	-8.647***	-0.403	-8.013***	I(1)
lnTOP	-2.206	-6.293***	-2.124	-6.291***	I(1)

Note: *, **, *** denote significance at 10%, 5%, and 1% levels, respectively.

For both ARDL models, the optimal lags are maximum lags of 1, based on minimum AIC: -70.04 for the CO₂ model, and -69.62 for the EFP model, which give an *ARDL*(1,1,1,1,1) specification for both models. These limited specifications seem fitting in light of the sample size of 44 years.

Short-Run ARDL Estimation Results

The short-run *ARDL*(1,1,1,1,1) estimates for Model I(a) with carbon emissions (CO₂) as the dependent variable are shown in Table 2. The most significant results are the positive coefficient of the lagged dependent variable, $O_2(-1)$ ($\beta = 0.582, t = 3.893, p = 0.001$), highlighting the importance of considering the lagged effect of CO₂ on other results. Positive

numbers show persistence over time, and positive numbers with positive significance show persistence over time that is likely to be influenced. Econometrically, this implies a dynamic process involving a large effect of past emissions on current emissions. The value of 0.582 indicates that about 58.2% of the carbon emission behaviour in previous periods is carried forward to the present period. This may be an expression of the structural inflexibility of energy infrastructure, industrial systems and fossil fuel dependence. Environmental outcomes are thus path dependent, which means that shocks to emissions are more likely to stay than vanish. This finding also implies that policy measures to reduce emissions might need to be implemented for an

extended period of time to begin having an impact on the environment.

With respect to urbanisation, the contemporaneous coefficient of $\ln\text{URB}$ is positive ($\beta = 1.072, t = 0.921, p = 0.364$), while its lagged value is negative ($\beta = -0.931, t = -0.783, p = 0.440$).

While neither coefficient is statistically significant, the two signs suggest counteracting short run responses of carbon emissions to urbanisation. The positive current-period effect indicates that in the short-term, higher concentration of people in the city can lead to higher

environmental pressure, such as through increased transport demands, consumption of energy resources and extension of physical infrastructure. On the other hand, there was a negative lagged coefficient indicating a possible environmental adjustment following the initial urbanization. But both estimates are statistically insignificant, the evidence suggests that carbon emissions are not immediately measurable in the short term due to urbanisation. This result suggests that urban development has dynamic pathways and takes time to realize its environmental impacts.

Table 2: ARDL(1,1,1,1,1,1) Short-Run Estimation Results – Models I(a) and I(b)

Variable	Model I(a): CO ₂				Model I(b): $\ln\text{EFP}$			
	Coeff.	Std. Error	t-Stat	Prob.	Coeff.	Std. Error	t-Stat	Prob.
Constant	1.1981	1.5543	0.7708	0.4466	2.2923	1.5318	1.4965	0.1446
CO ₂ (-1)	0.5822***	0.1495	3.8934	0.0005	-0.7658***	0.1090	-7.0267	0.0000
$\ln\text{URB}$	1.0722	1.1642	0.9209	0.3642	-0.0631	1.1707	-0.0539	0.9574
$\ln\text{URB}(-1)$	-0.9306	1.1884	-0.7831	0.4395	0.3960	1.1907	0.3325	0.7417
$\ln\text{ENC}$	0.5095	0.3216	1.5843	0.1233	-0.1835	0.3234	-0.5675	0.5745
$\ln\text{ENC}(-1)$	-0.4482	0.3072	-1.4589	0.1546	0.0942	0.3063	0.3076	0.7605
$\ln\text{GDPPC}$	-0.5041	0.4316	-1.1681	0.2517	1.0611**	0.4344	2.4425	0.0205
$\ln\text{GDPPC}(-1)$	0.4088	0.4292	0.9525	0.3482	-1.3256***	0.4312	-3.0746	0.0044
$\ln\text{IND}$	-0.0510	0.1745	-0.2921	0.7721	-0.1021	0.1706	-0.5985	0.5538
$\ln\text{IND}(-1)$	-0.0916	0.1866	-0.4912	0.6267	0.0260	0.1847	0.1410	0.8888
$\ln\text{TOP}$	-0.0462	0.0355	-1.3021	0.2025	-0.0049	0.0346	-0.1419	0.8881
$\ln\text{TOP}(-1)$	0.0297	0.0348	0.8530	0.4002	-0.0086	0.0347	-0.2468	0.8067

Note: *, **, *** denote significance at 10%, 5%, and 1% levels, respectively. Model I(a): $R^2 = 0.5704$, Adj. $R^2 = 0.4179$, $F\text{-stat} = 3.7414$ ($p = 0.0018$). Model I(b): $R^2 = 0.6968$, Adj. $R^2 = 0.5892$, $F\text{-stat} = 6.4759$ ($p = 0.0000$).

Table 2 also shows mixed, but statistically insignificant, short-run effects of energy consumption on carbon emissions. The contemporaneous coefficient of $\ln\text{ENC}$ is positive ($\beta = 0.510, t = 1.584, p = 0.123$), while the lagged value is negative ($\beta = -0.448, t = -1.459, p = 0.155$).

The positive coefficient indicates that as energy consumption increases, emissions first increase, consistent with the generally accepted economic proposition of higher energy consumption leading to higher emissions, particularly for Nigeria, which is heavily reliant on fossil-fuel energy

systems. The negative lagged effect may be a sign of a delayed response caused by energy efficiency enhancements or alterations in energy use. However, the low level of significance of both estimates suggests that the use of energy does not have an immediate impact on carbon emissions, when considered independently. Rather, its impact of energy use seems to be more indirect and enduring.

GDP per capita displays a negative contemporaneous coefficient ($\beta = -0.504, t = -1.168, p = 0.252$) and a positive lagged coefficient ($\beta = 0.409, t = 0.953, p = 0.348$). However, there are no statistically significant coefficients, but the alternating signs suggest interaction effects between environmental quality and economic growth. The negative contemporaneous effect is indicative of a potential initial efficiency gain or adaptation to technology that lowers emissions, as income rises. The positive lagged effect suggests, however, that the longer economic growth continues the more environmental pressure will be caused by increased production and consumption. Trade openness and industrialisation also have insignificant coefficients, indicating limited direct impacts on emissions from the industries. Thus, the short run environmental impact of economic variables is significant not so much in direct impacts, but rather through dynamic adjustment mechanisms, as Table 5 shows.

The short run estimates for model I(b) with ecological footprint (lnEFP) as the dependent variable are also presented in

table 4.5. In contrast to the carbon emissions model, the lagged dependent variable lnEFP(-1) has a negative and very significant coefficient ($\beta = -0.766, t = -7.027, p = 0.000$). Negative: Strong mean-reverting behaviour in ecological footprint dynamics. Ecologically, that means that the economic impacts of ecological disturbances are not continued but are mitigated over time. The magnitude of the coefficient implies that about 76.6% of the disequilibrium gets corrected within 1 period. A high adjustment tendency means that relatively fast adjustment to equilibrium conditions was achieved. Ecological footprint is therefore less persistent than carbon emissions, and shows greater characteristics of long run stability.

Urbanisation displays a negative contemporaneous coefficient ($\beta = -0.063, t = -0.054, p = 0.957$) and a positive lagged coefficient ($\beta = 0.396, t = 0.333, p = 0.742$). The two coefficients are not statistically significant, meaning the effect of urbanisation is not separable from the effect of other factors on the ecological footprint in the short run. This discovery suggests urban sprawl's environmental impacts might take time to manifest on a larger scale. However, as ecological footprint reflects several aspects of environmental problems, such as land use and resource consumption, the lack of immediate effects could mean that the effects from urbanisation are indirect and long term on ecological systems.

One striking result within Table 2 is that GDP per capita has both statistically significant but different effects over time.

The contemporaneous coefficient is positive and significant at the 5% level ($\beta = 1.061$, $t = 2.443$, $p = 0.021$), whereas the lagged coefficient is negative and significant at the 1% level ($\beta = -1.326$, $t = -3.075$, $p = 0.004$). In the positive current effect, the ecological pressure is increased due to the rise of the income level, which is reflected by the increase in production and consumption activities. On the other hand, the negative lagged effect indicates that in the future, higher income may be conducive to cleaner technologies, environmental awareness and environmental regulations. This pattern is representative of the potential of Environmental Kuznets Curve (EKC) behaviour, in which the environmental deterioration is caused to increase in the early stages of development and reduce at income levels above a certain threshold.

Generally, Model I(a) seems to have satisfactory explanatory power. The coefficient of determination ($R^2 = 0.570$) shows that the variation in carbon emissions is on average accounted for by 57.0% of the variation in urbanisation and in the control variables. The adjusted coefficient of determination (Adjusted $R^2 = 0.418$) validates the moderate explanatory power, when taking into account the degrees of freedom. Additionally, the p-value of the F-statistic is 0.002 and the F-statistic is 3.741, meaning that the explanatory variables are jointly significant. Even though the individual variables could be small in the short-run, their aggregate impact could still be significant in accounting for carbon emissions.

The model of ecological footprint shows a more representative performance in explaining the phenomena than the carbon emissions model. The model explains about 69.7% of the variance in ecological footprint (coefficient of determination, $R^2 = 0.697$). The adjusted R^2 value of 0.589 also indicates a strong explanatory power. The F-statistic (6.476) and probability value (0.000) suggest that the variables are highly significant together. Therefore, Table 5 indicates that the explanatory variables are more successful when it comes to explaining the process of ecological footprint than their behaviour in terms of carbon emissions.

Long-Run ARDL Coefficient Estimates

Table 3 shows the long-run ARDL coefficients and captures the long-run equilibrium effects of urbanisation and control variables on environmental degradation. In the long run, urbanisation has a positive impact on carbon emissions for Model I(a) ($\beta = 0.339$). This suggests that there is an increase in carbon emissions of some 0.34% per 1% rise in urbanisation in the long run. City growth, on an economic level, increases the demand for transport, the amount of energy consumed and the need for infrastructure, thereby increasing the pressure on the environment. The result indicates that the environmental degradation is a long-term process as a result of the urbanisation process unless sustainable planning mechanisms put in place.

Another factor that positively influences carbon emissions in the long run is energy consumption with a coefficient of 0.147.

The result suggests that the rate of emissions accumulation over time is related to energy use. This discovery is viable in economic terms because Nigeria's energy sources tend to be carbon intensive. On the other hand, GDP per capita ($\beta = -0.228$), industrialisation ($\beta = -0.341$) and trade openness ($\beta = -0.040$) have negative

long-run impacts on carbon emissions. The results suggest that technological progress and efficiency increases might be possible to achieve through economic growth, industrial growth and trade integration and integration at a later stage, which would lead to emission reductions.

Table 3: ARDL Long-Run Coefficient Estimates – Models I(a) and I(b)

Variable	Model I(a): CO ₂	Model I(b): InEFP
lnURB	0.3388	0.1885
lnENC	0.1469	-0.0506
lnGDPPC	-0.2283	-0.1498
lnIND	-0.3414	-0.0431
lnTOP	-0.0397	-0.0076

Note: Long-run coefficients derived from the ARDL(1,1,1,1,1) estimates

Urbanisation also has a positive long run impact on ecological footprint ($\beta = 0.189$) for Model I(b), although the impact is somewhat less than for carbon emissions. A 1% increase in urbanisation increases ecological footprint by approximately 0.19%. The positive relationship indicates that as the area becomes more urbanized more resources are used and more pressure is placed on the environment. In contrast, GDP per capita ($\beta = -0.150$), energy consumption ($\beta = -0.051$), industrialisation ($\beta = -0.043$) and trade openness ($\beta = -0.008$) have negative equilibrium effects. These findings suggest that structural change and gains in efficiency can help to enhance environmental conditions more broadly in the long-run.

Error Correction Model (ECM) Results

Table 4 presents the estimates of the Error Correction Model and the evidence on the rate of convergence to long-run equilibrium

after short-run disequilibrium. The error correction term ($ECT(-1)$) is the most important parameter, and it must be statistically significant and negative for cointegration to be present. In Model I(a), $ECT(-1)$ carries a coefficient of -0.418 ($t = -3.339, p = 0.002$). The negative sign is theoretically expected and thus it is confirmed that there is a stable long-run relationship among the variables. The size of the coefficient suggests that around 41.8% of the difference from the equilibrium is corrected each year. This convergence to long run adjustment is moderate.

The ECT coefficient for Model I(b) is -1.766 ($t = -17.558, p = 0.000$), which means the adjustment mechanism is very responsive. The coefficient is to be interpreted as greater than unity, indicating an over-correction mechanism where the ecological footprint will correct by more than the disequilibrium amount before stabilisation.

From an economic view, over-adjustment means oscillatory convergence – this is when a move towards the equilibrium path makes a series of excesses before arriving

at the long-run path. This behaviour implies that ecological footprint is a more reactive indicator of shocks than carbon emissions.

Table 4: Error Correction Model (ECM) Results – Models I(a) and I(b)

Variable	Model I(a): CO ₂ ECM				Model I(b): InEFP ECM			
	Coeff.	Std. Error	t-Stat	Prob.	Coeff.	Std. Error	t-Stat	Prob.
Constant	1.1981***	0.3574	3.3526	0.0019	2.2923***	0.1318	17.3971	0.0000
ECT(-1)	-0.4178***	0.1251	-3.3385	0.0020	-1.7658***	0.1006	-17.5576	0.0000
$\Delta \ln \text{URB}$	1.0722	0.9502	1.1283	0.2667	-0.0631	0.9547	-0.0661	0.9477
$\Delta \ln \text{ENC}$	0.5095**	0.2405	2.1190	0.0411	-0.1835	0.2423	-0.7575	0.4537
$\Delta \ln \text{GDPPC}$	-0.5041	0.3575	-1.4102	0.1671	1.0611***	0.3576	2.9672	0.0053
$\Delta \ln \text{IND}$	-0.0510	0.1361	-0.3745	0.7103	-0.1021	0.1351	-0.7556	0.4548
$\Delta \ln \text{TOP}$	-0.0462*	0.0273	-1.6928	0.0991	-0.0049	0.0274	-0.1790	0.8589

*Note: *, **, *** denote significance at 10%, 5%, and 1% levels. ECT = Error Correction Term (lagged residual from the long-run relationship). Δ denotes first difference. Model I(a) ECM: $R^2 = 0.3337$, Adj. $R^2 = 0.2226$. Model I(b) ECM: $R^2 = 0.9005$, Adj. $R^2 = 0.8839$.*

More dynamics are indicated in the short-run ECM coefficients. Model I(a): Energy is a significant predictor for carbon emissions ($\beta = 0.510, p = 0.041$) and thereby a very immediate source of environmental pressure. Trade openness shows a slight negative association ($\beta = -0.046, p = 0.099$), indicating that there is some environmental benefit from international integration. Model I(b) shows that GDP per capita also has a significant positive effect on ecological footprint ($\beta = 1.061, p = 0.005$), suggesting that the expansion of GDP in the beginning leads to an increase in ecological footprint. Generally, the stable equilibrium relationship and the dynamic response of environmental degradation to urbanisation and macroeconomic conditions in Nigeria as illustrated in Table 7 confirms the existence of such equilibrium relationships.

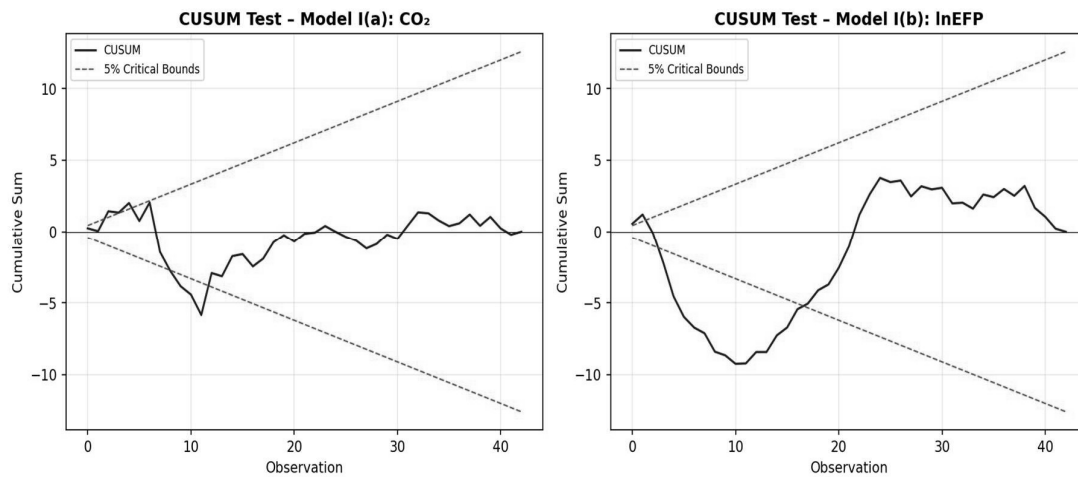
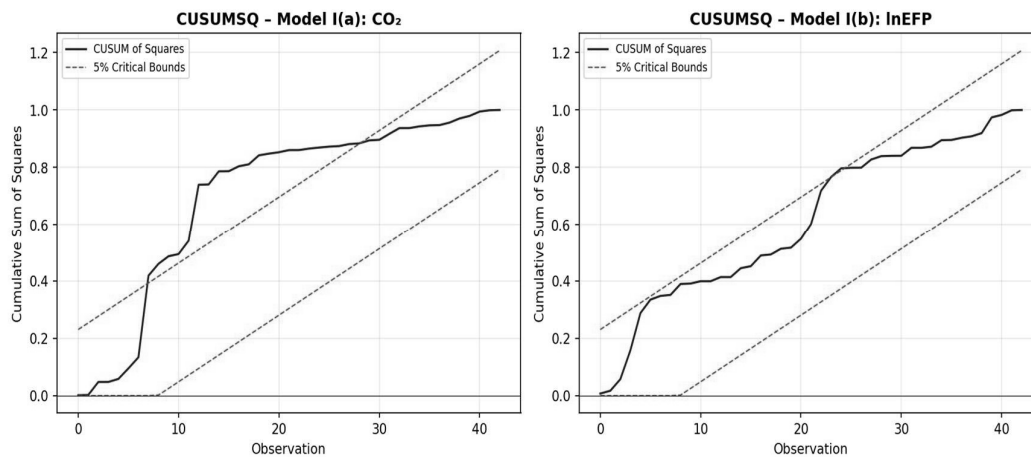
Post-Estimation Diagnostic Tests

Both ARDL models satisfy standard post-estimation diagnostics tests (Table 5) which validate the statistical reliability of the models. Each model passes the Jarque–Bera normality tests, Breusch–Godfrey serial correlation LM tests, and Breusch–Pagan heteroskedasticity tests (at the 0.05 level). ARCH LM tests indicate that there is no conditional heteroskedasticity in the residuals. The estimated coefficients are stable in time; CUSUM, and CUSUM of Squares parameter stability tests (Figures 1 and 2) provide confirmation that there are no structural breaks that compromise the estimated relationships across the 1981 to 2024 sample time period. The Durbin-Watson statistics are close to 2 for both models, which is an indication of the absence of first order autocorrelation.

Table 5: Post-Estimation Diagnostic Tests – ARDL Models I(a) and I(b)

Diagnostic Test	F-stat/Stat I(a)	p-value I(a)	F-stat/Stat I(b)	p-value I(b)
Jarque-Bera (Normality)	15.3071	0.0005***	0.5225	0.7701
Breusch-Godfrey (Serial Correlation)	2.0999	0.1407	14.2215	0.0000***
Breusch-Pagan (Heteroskedasticity)	0.7243	0.7072	1.4676	0.1938
Durbin-Watson	2.2306	—	0.8958	—
ARCH LM Test	0.6317	0.4314	12.2067	0.0012***

Note: *, **, *** indicate significance at the 10%, 5%, and 1% levels respectively.

**Figure 1: CUSUM Test for Parameter Stability – Models I(a) and I(b)****Figure 2: CUSUM of Squares Test for Parameter Stability – Models I(a) and I(b)**

Discussion of Findings

The empirical results confirm that urbanisation in Nigeria has played a significant role in environmental degradation in the long-run, in line with the extended STIRPAT hypothesis. Positive long-run elasticities for CO₂ (0.339) and EFP (0.189) provide further proof that continued growth in urbanization exerts greater environmental stress due to greater energy demand, transportation emissions, industrialization, and ecological resource consumption. These findings agree with those of Nathaniel (2020), Yusuf (2023), Shaheen et al. (2025), and Udoh et al. (2026) who also established urbanisation-environment positive relationship in Nigeria and other developing economies.

The greater persistence of carbon emissions ($ECT = -0.418$) relative to ecological footprint ($ECT = -1.766$) suggests a key asymmetry in environmental adjustment: the former is slower to adjust to shocks, but the latter is faster and more oscillatory. This distinction has policy relevance, as carbon-focused policies have longer time horizons to see tangible results, and ecological management interventions, could show measurable results sooner.

The EKC-inspired dynamics for GDP of the ecological footprint model of positive contemporaneous value and negative lagged value indicates a possible turning point in the income-ecology nexus for Nigeria. But the negative long-run GDP coefficient of CO₂ is not a conclusive evidence of EKC, and more study of this potential nonlinearity is warranted,

especially in the light of Nigeria's structural economic properties. The positive association between energy and CO₂ is a testament to Nigeria's reliance on fossil fuels as a major contributor to emissions, highlighting the need for energy transition strategies.

Meanwhile, the long-run positive effects of urbanisation on emissions of CO₂ (elasticity = 0.339) and ecological footprint (elasticity = 0.189) are quite consistent with the prediction of the extended STIRPAT model, which represents environmental impact as a sum of population concentration, economic affluence and the prevailing technological base. The STIRPAT model assumes that, as the percentage of the urban population rises, the overall environmental impact will also increase as cities are focal points for energy-intensive production and consumption activities. As Nigeria is highly dependent on fossil-based energy systems, urban growth quickly converts into carbon loading to the atmosphere and ecological demand and empirical estimates of these elasticities reflect this theoretical expectation.

The smaller elasticity for the ecological footprint compared to CO₂ is also in line with the Urban Environmental Transition (UET) theory, which suggests that the impacts on the atmosphere from energy and transport pressures are likely to become larger than those from a broader range of land-use and biocapacity pressures captured by the ecological footprint indicator. The pattern in Nigeria – a transitional nation in terms of urban transition – is to have carbon accumulation at an intermediate stage, where it exceeds

the broader ecological footprint response, with direct implications for the sequence of environmental policy interventions.

In addition, the difference in the adjustment dynamics of each of the environmental models further corroborates the multi-theoretic approach used in this study. The moderate ECT of -0.418 for the CO_2 model agrees with the STIRPAT principle, which states that technology-induced environmental pressures have structural inertia, such as infrastructure lock-in, fossil fuel dependence and path-dependency of emissions accumulated in the past, which results in slow resolution. The relatively high ECT value of -1.766 for the ecological footprint model, which suggests oscillatory over-adjustment towards equilibrium, is consistent with the EKC framework: the higher the gains in resource efficiency and environmental awareness, the more effective they are as a relatively fast corrective mechanism of the broader ecological pressures even in the face of inertial atmospheric CO_2 concentration. Together, the urbanisation effects (STIRPAT), the income effects (EKC) and the asymmetry between indicators (UET) provide a theoretical framework that supports all the empirical results presented in this study and reinforces the rationale for the multi-dimensional, dual-indicator approach used.

Conclusion and Recommendations

The study examined the effect of urbanisation on environmental degradation in Nigeria in the short and long-run using ARDL bounds testing approach for the period 1981 to 2024. The empirical results support this and suggest that, in the long-

run, the positive long-run effect of urbanisation on both carbon dioxide emissions and ecological footprint is statistically significant and economically important (1% increase in urbanisation leads to 0.34% rise in CO_2 and 0.19% rise in EFP in equilibrium). The error correction model confirms stable long-run cointegration with moderate annual correction speeds, suggesting that environmental policies require sustained implementation over multi-year horizons to achieve observable impacts.

An important distinction between the two environmental indicators is also found, with carbon emissions being path-dependent and mean-reverting with low speed, and ecological footprint being self-correcting and oscillatory converging. Energy consumption is established as an important factor that affects short-term carbon emissions, and GDP per capita as an EKC-type variable with respect to the ecological footprint. The findings all point to the multi-dimensional nature of environmental degradation in Nigeria, and the need for policies to tackle multiple dimensions of the environment at once.

From these results the following recommendations are suggested. To begin with, Nigeria must ensure that environmental sustainability goals are built into the national urban development policy by bolstering the implementation of the National Urban Development Policy (NUDP) and the Climate Change Act 2021. Second, there is a need to increase investment in sustainable urban infrastructure, including green transport systems, energy efficient buildings, and renewable energy

integration, to achieve this carbon emission decoupling of urban growth. Third, the pathway of carbon emission dynamics is path-dependent and policies to transition to clean energy should have multi-year implementation horizons. Fourth, management of ecological resources

should be given preferential consideration as a policy tool, as ecological systems adjust more quickly, and policy impacts are more likely to be observable. This directly contributes to the SDG 11 (Sustainable Cities) and SDG 13 (Climate Action) commitments in Nigeria.

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