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Rural Population, Economic Growth And Co2 Emissions: Testing The Environmental Kuznets Curve Hypothesis In Nigeria

by
Koginam, Owudumopu Alex
Department of Economics and Development Studies
Federal University Otuoke, Bayelsa State, Nigeria.
E-mail: aleraplus@gmail.com; Phone No:+234-7039043940

Abstract
This paper examines the effects of rural population and economic growth on CO2 emissions, with particular focus on the validity of the inverted U-shaped environmental Kuznets curve hypothesis in Nigeria from the year 1970 to 2022. The paper applied the Autoregressive Distributed Lag technique in the analysis of the specified regression model. The result of the bound test revealed evidence of cointegration between rural population, economic growth and CO2 emissions. The findings show that rural population has a small but positive influence on CO2 emissions. In contrast, the study found that rising incomes significantly improves environmental quality in the long run which validates the presence of the EKC. The paper therefore recommends that the rural population should be better orientated on the ways some of the primary sector activities they are engaged in contribute to CO2 emissions into the atmosphere. Moreover, the government can take significant steps to improve environmental quality by encouraging the human development of the rural population. This may contribute to reverse the effect of rural livelihood activities on the environment.

KEYWORDS: Rural Population, Economic Growth, CO2 Emissions, ARDL, EKC

Introduction

Present environmental conditions are a source of worry to the government of many countries across the world, and this is not unconnected to the significant challenges been posed to the health, per capita income and social wellbeing of individuals by climate change. In fact, the situation seems to have heightened since the turn of the century, necessitating global attention on the drivers of environmental pollution in the world. Nathaniel and Iheonu (2019) asserts that climate change is linked to energy consumption and the resultant effects of green-house gas emissions on the environment. The United States Environmental Protection Agency (EPA) defines greenhouse gases as gases that trap heat in the atmosphere; predominant of which is are emissions from carbon dioxide (CO2) (EPA, 2025).

Carbon dioxide (CO2) emission channels to the atmosphere are majorly through fossil fuel consumption (coal, crude oil and natural gas), but could also be transferred to the environment and cause distortion in its natural structure through human activities such as the felling of trees, deposition of solid waste, bush burning, as well as chemical reaction of certain production activities (example: cement production) on the atmosphere (EPA, 2025). Consequently, while it is understandable that high energy demand for industrial, residential and transportation activities in urban areas may exacerbate air pollution levels in urban locations; this independently, does not reduce the influence that rural livelihood activities may exert on the level of CO_2 emission especially in developing countries were most of the rural population predominantly engage in primary sector occupations and burn burning activities that also transfer carbon dioxide (CO_2) to the atmosphere.

For instance, Nigeria is the most populous country in Africa, with more than one third (45.72%) of its total population living in the rural areas of the country (World Bank, 2023) and rural livelihoods are mainly in the primary sectors of the economy. Thus, such livelihood activities like farming, animal husbandry, lumbering and fishing actively engaged by most inhabitants of rural areas across the country. While these activities generate incomes for rural households, they nonetheless lead to the conversion of natural ecosystems with large areas of natural forests for farming and lumbering activities, which contributes to deforestation and the emission of CO_2 to the atmosphere.

Direct observation of agricultural practice suggest that it is a major determinant of deforestation in the country. In some of these rural communities, natural forest land areas are converted to small-fragmented farmlands for agricultural purposes by individuals and households. These activities devalue the natural eco-system. Li, et at, (2024) however suggest that while deforestation is one cause of CO_2 emissions in rural areas, it is possible where land transfers in rural areas lead to the consolidation of small-scale farms and formerly fragmented lands into larger specialised farming enterprises, to cause the decline in rural CO_2 emission levels due better farm land management practices; but for rural areas with high intensity agriculture activity and reduced forest areas, the influence on CO_2 emissions levels may be significant and positive. Therefore, the imperative of a thorough understanding of the impact of rural population in the design of effective policies to reduce environmental pollution cannot be overemphasized.

The influence of economic activities on CO_2 emission has also been the focus of studies by many scholars albeit with divergent results. While many of these studies have argued that rising economic activities goes hand in hand with increased levels of CO_2 emission especially in the short run time period (Osadume & University, 2021; Olusanya & Musa, 2018; Teklie & Yakmur, 2023;), others suggest that in the short run, economic growth does not have significant impact on CO_2 emissions (Espoir, et al., 2023; Musa & Maijama'a, 2020). Moreover, empirical studies also reveal that higher national income levels are favorable to the demand for environmental sustainability and favour reduced pollution levels in the long run (Onofrei, et al., 2022; Li & Haneklaus, 2021), which is in tandem with the proposition of the environmental Kuznets curve (EKC) hypothesis.

The present study contributes to these set of studies that analyzed the antecedents of CO2 emissions in two folds: first, the study employs data sequences spanning from 1970 to 2022 to evaluate the impact of population as a diver of CO2 emission in Nigeria. The use of such a long-time span is necessary to show the impact of rural population on CO2 emissions in the country. Secondly, the study tests the validity of the environmental Kuznets curve hypothesis. Accordingly, the study proposed the following hypotheses:

H_{o1}: *Total rural population and CO2 emissions are negatively correlated.*

The impact of rural population on CO2 emissions may be mitigated by the spread of information on best agricultural and livelihood practices among the rural population. This is possible in an economy with stable levels of economic growth and per capita income. In such an economy, promoting green agricultural development and the use of modern techniques in place of environmental unfriendly practices as bush burning, excessive deforestation of natural forests, use of dangerous pesticides and fertilizers can be easily implemented among the rural population. Moreover, the level of human development of people of the population could influence rural livelihood practices and therefore impact on the level of CO2 emissions in the country. Accordingly, drawing on this theoretical analysis, the second hypothesis is stated as:

H_{o2}: *The Environmental Kuznets curve proposition is not valid in Nigeria.*

This study is significant as it quantifies the influence of rural population and output growth on CO2 emissions, as well as reveals evidence of the environmental Kuznets curve hypothesis in Nigeria. The rest of the paper is laid out as follows. Section 2 is an exposition on previous scholarly literature on the subject-matter and in Section 3, the methodology of the study is discussed. Result and discussion of findings is in Section 4, while Section 5 concludes the study as well as makes policy

2.0 Literature Review

Theoretical Framework: Environmental Kuznets Curve (EKC)Theory

The environmental Kuznets curve theory is one of the foremost theories that connects the influence of human activities with changes in the quality of the environment. The EKC as posited by Grossman and Krueger (1995) asserts that growth in real output could lead to environmental pollution during the developmental phase of a country. However, as the economy expands and per capita income stabilizes, the intensity of the effect of economic activities on the environment may begin to decrease and eventually change. This is because of the possibility of economic development to positively contribute to human development through an expansion in knowledge and the number of educated people who are better able to understand the imperative of sustainable environment and the need to promote eco-friendly livelihoods. Therefore, with improved human development leading to better understanding of the consequences of environmental pollution, it would engender environmental protection activities that would eventually lead to the decline in CO_2 emissions in the long run.

The EKC basically evaluates the magnitude of correlation that exists between rising per capita income - which is a product of increased production activities- and environmental pollution. Stern (2003) asserts that the proposition of the classical Environmental Kuznets Curve hypothesis explained diagrammatically appears as an inverted U-shaped Curve. The EKC is depicted in Figure 1 below:

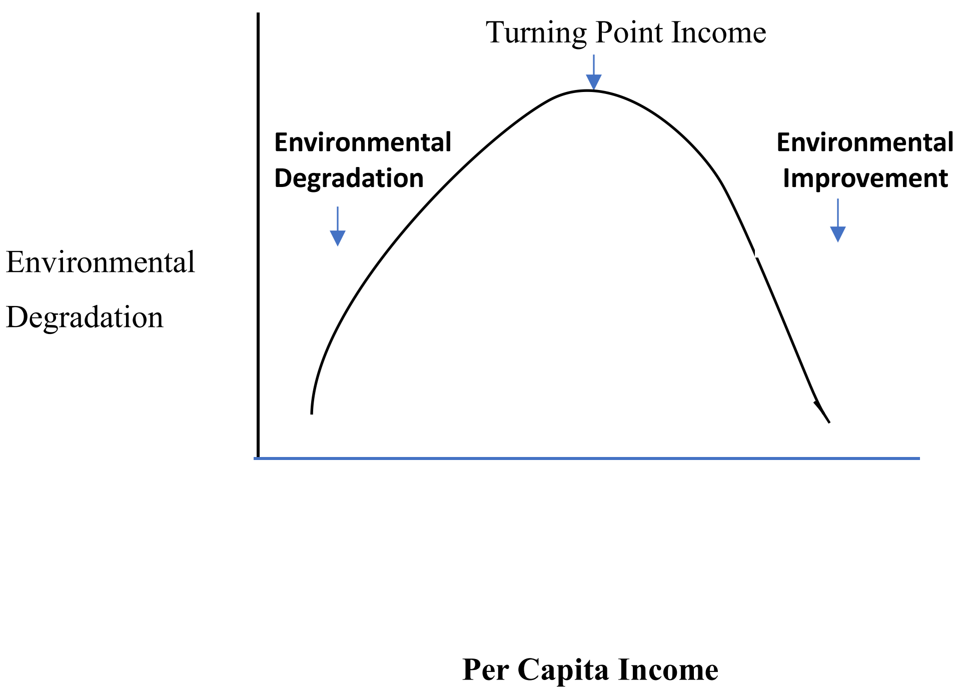


Figure 1: Environmental Kuznets Curve

The EKC hypothesis as depicted in Figure 1 suggests that in the short run, environmental pollution is likely to increase as economic activities rise. However, with rising per capita incomes accompanying economic growth, a certain level of income may be passed where the quest for economic growth also aligns with the objective of environmental remediation. Consequently, this would lead to declining levels of environment pollution amid rising economic growth. Hence, suggesting that the relationship between level of income and environmental pollution could be described by an inverse-U-shaped curve. The rise and eventual decline of environmental pollution at latter stages in the growth trajectory may be attributed to the scale effect, composition effect and the technology effect. These three effects separately show how inputs employed in the production mix, change in the structure of economic activities and human development could exert influence on the natural environment.

Empirical Literature

There are dozens of empirical literatures that have examined how drivers of environmental pollution impact on CO2 emissions. However, this review of related works on the nexus between rural population, economic growth and CO2 emissions concentrates on two strands; the first is on the impact of population and economic growth on environmental pollution; while the second is on validity of the EKC in Nigeria.

On the first strand, Shaari, et al (2021) in their study of impact of rural population growth, energy use and economic growth on CO2 emissions in selected developing countries observed that rural population growth does not cause significant change in CO2 emissions as much as economic growth and energy use in the long run; and rural population does not influence CO2 emissions in the short run. Pan, et al (2021) examined how changes in the population structure affects carbon emissions in China. The study was from 1995 to 2018 and ridge regression method was used in the estimation of the specified models. The study found that population size and structure as well as the level of consumption and employment were significant determinants of CO2 emissions in the country. The findings also revealed that while population size has the most significant impact on CO2 emission, the influence of the structure of population consumption on CO2 emissions was negative during the period of study.

In a similar study, Akorede and Afroz (2020) examined the relationship between urban population, economic growth and energy consumption in Nigeria. The study utilised the autoregressive distributed lag (ARDL) method and spanned from 1970 to 2017. The findings of the study revealed that economic growth has a positive impact on CO2 emissions in the short run, but this was not the same for urban population whose influence on CO2 emissions was significantly negatively both in the short run and long run time periods. Alaganthiran and Anaba (2022) studied the effects of economic growth on carbon emissions in twenty selected countries in Africa from 2000 to 2020. The panel study found out that there was significant relationship between economic growth, population, energy consumption and carbon emissions in the period under review. Moreover, the findings show that a 1% increase in economic growth increased carbon emissions by as much as 0.02%.

Aye and Edoja (2017) empirically examined the effect of economic growth on CO2 emission in 31 developing countries in Africa. The result of the study indicated that economic growth has a negative effect on CO2 emissions in regimes with low growth levels, but the findings were different in regimes with high economic growth as higher marginal effects were found. Osadume and University (2021) examined the impact of economic growth on carbon emissions in selected countries in sub-Saharan West Africa. The study spanned from 1980 to 2019. The study observed that economic growth positively and significantly impacted on the level of CO2 emissions in the focus countries. Li, et al (2021) in their study of per capita emissions and the effects of economic growth, social and trade changes in 147 countries from 1990 to 2015. The study noted that a 1% increase in economic activities exacerbated air carbon dioxide emissions by 0.93%.

Musibau, et al (2020) in their study of the nexus between environmental degradation, energy use and economic growth, noted that the impact of the rise in economic activities on CO2 emissions was positive and significant only found in the short run, while in the long run, economic growth has a negative effect on CO2 emissions. Lin, et al (2015) examined the impact of industrialization on CO2 emissions in Nigeria. The study spanned from 1980 to 2011 and utilised the vector error correction model (VECM) estimation method. The findings showed that industrial value-added has a significant and inverse relationship with CO2 emissions in the country. However, GDP per capita and population exerted positive influence on CO2 in the county. Cao and Liu (2023) studied the impact of population characteristics on carbon dioxide emissions in China. The study was from 2000 to 2019 and utilised the STIRPAT model. The results showed that that population aging and population quality restrained CO_2 emissions from transportation, but the negative effects of population aging were indirectly caused by economic growth and transportation demand. In addition, the aggravation of population aging as well as its influence on transport CO_2 emissions changed and presented a U-shaped curve.

Furthermore, previous empirical works exist in Nigeria that have tested the validity of the environmental Kuznets curve hypothesis. For instance, Olatayo, et al (2019) tested the validity of the Kuznets curve hypothesis in their study of economic growth and environmental degradation in Nigeria. The authors concluded that the Kuznets proposition was not valid in the case of Nigeria as economic growth increased environmental degradation in the long run.

Adelegan and Otu (2020) examined the nexus between environmental quality and economic development in Nigeria under the parameter of the Kuznets curve hypothesis. The empirical study was from 1980 to 2018. The findings of the study lend support to the validity of the EKC proposition in the country. the study concluded with the recommendation of a harmonious mix of environmental and economic policy tin such ways that would enhance the value of the environment without stagnating the economy. Johnbosco (2019) investigated the validity of the Kuznets curve hypothesis in the domestic economy. The findings suggested that the inverted U-shaped Kuznets curve proposition was valid in the case of Nigeria.

In a similar but slightly different approach, Nketiah, et al (2023) comparatively tested the validity of the Kuznets curve hypothesis in Nigeria and Ghana. The study employed tine series sequences from 1980 to 2019. Moreover, the ARDL as well as the DOLS methods of estimation were used in the study. The findings showed that the inverted U-shaped curve hold for Nigeria, but the same was not true for Ghana, during the period under study. The authors therefore suggested that focus should be given to environmental legislations in both countries so as to enable them attain the specified sustainable development goals.

Omodamwen and Obainoke (2024) assessed empirically the nexus between economic growth and CO_2 emissions in Nigeria. The study was 1982 to 2022. The authors employed the ARDL estimation method in the analysis. The study found no empirical validation for the EKC hypothesis in the country. The findings showed that economic growth increases economic activities both in the short and long run time periods. Haliru, et al (2020) employed quintile panel regression estimation method in the investigation of the inverted U-shaped Kuznets curve hypothesis in countries of the Economic Community of West Africa States (ECOWAS). The study spanned from 1970 to 2017. The empirical findings of the study suggested that rather than an inverted U-shaped relationship between economic growth and carbon dioxide (CO_2) as expounded in the EKC, it was a U-shaped relationship between economic growth and Carbon dioxide (CO_2) emissions that holds in the low, middle and high-emissions countries.

Ouédraogo, et al (2021) studied the effects of oil resources on environmental quality under the prism of the environmental Kuznets curve hypothesis. The study utilised a panel data approach comprising of eleven oil producing countries in Africa. The study found out that oil resources abundance devalued the environmental quality of Angola, but abated CO_2 emissions in Algeria, Gabon, Morocco, and Nigeria. Contrarily, energy consumption escalated pollution in the Congo Democratic Republic (COD), Côte d'Ivoire (CIV), Gabon, Morocco, and Tunisia. The findings therefore supported the EKC hypothesis only Nigeria, in Cameroon and Côte d'Ivoire. However, the results indicated evidence of a U-shaped curve in Algeria and Morocco, respectively.

3.0 Methodology

The broad objective of the study is to estimate the nexus between of rural population, real output and CO_2 emissions in Nigeria. Accordingly, historical sequences from 1970 to 2022 on total rural population (RURAL_P), economic growth (proxied by per capita GDP) and CO_2 emssions (proxy for environmnetal pollution) were obtained from the World Bank Development Indicators, 2023. In line with the assumptions of the inverted U-shaped Kuznets environmental curve hypothesis, a non-linear quadratic equation of the following functional is specified:

$$CO2 = f(RURAL\_P, GDP\_P, GDP\_P^2) \quad . \qquad 3.1$$

Where:

CO2 = carbon dioxide emission (proxy for environmental pollution)
RURAL_P = Total rural population
GDP_P= Gross domestic Product Per capita
GDP_P^2= Square of GDP per capita

The econometric specification of the environmental pollution model in equation 3.1 is stated as:

$$CO2_t = \propto_0 + \propto_1 RURAL\_P_t + \propto_2 GDP\_P_t + \propto_3 GDP\_P\text{^}2_t + \propto_4 \mu_t \quad . \quad . \quad 3.2$$

The theoretical expectations for the coefficients of equation 3.2 are $\propto_1 < 0$; $\propto_2 > 0$; $\propto_2 > 0$; $\propto_3 < 0$. Moreover, to decide on the appropriate econometric procedure that would be employed in the estimation of the environmental pollution function, the Augmented Dickey Fuller (ADF) unit root test was used to determine the order of integration of the variables. The result shows a mixed order of integration (See: Table 3). Accordingly, since the Autoregressive Distributed Lag approach (ARDL) permits estimation of variables with mixed order of integration, it was employed in the econometric analysis of the resource depletion model.

Pesaran and Shin (1999) developed the ARDL for the cointegration analysis of models with variables having mixed unit root properties. Improvements in the ARDL method ensures the estimation of the dependent and explanatory variables with different lags as well as the use of fixed regressors, which is impossible in other conventional methods used for the test of cointegration. Moreover, the ARDL gives robust estimates even for small data sets, and is therefore suitable for the present study that spans from 1970 to 2022, a period of 53 years.

The general specification of the ARDL(p,q) is as follows:

$$\Delta y_t = a_0 + \sum_{i=1}^{p} a_{1i} \Delta\gamma_{t-1} + \sum_{j=1}^{q} \gamma_j X_{t-j} + \varepsilon_t \quad . \quad 3.3$$

where y_t is the dependent variable, X_t is a vector of the dynamic explanatory variables which and ε_t is the error term that should be normally distributed with zero mean and constant variance $\varepsilon_t \sim N(0, \sigma^2)$, p and q are the number of lags for dependent and explanatory variables; respectively.

To test for whether there is long-run relationship (cointegration) between y_t and X_t, the bound test equation is specified as follows:

$$\Delta y_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta\gamma_{t-1} + \sum_{j=1}^{q} \varphi_{1i} \Delta X_{t-j} + \omega_0 \gamma_{t-1} + \omega_1 X_{t-1} + \vartheta_t \quad . \quad . \quad 3.4$$

where β_1, and φ_1 are the parameters of the short-run relationship; ω_0 and ω_1 are the parameters of long-run relationship. Accordingly, cointegration between y_t and X_t exists if the null hypothesis, H_0: $\omega_0 = \omega_1 = 0$ is rejected against the alternative H_1: $\omega_0 \neq \omega_1 \neq 0$.

In addition, the existence of cointegration relationship in the models, also necessitates an evaluation of the error correction model (ECM). The equation of the ECM is specified as follows:

$$\Delta y_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \gamma_{t-1} + \sum_{j=1}^{q} \varphi_{1i} \Delta X_{t-j} + \emptyset_0 ECM_{t-1} + \vartheta_t \quad . \quad . \quad 3.5$$

In actual fact, the term of the ECM_{t-1} is derived from the lagged value of the error term (μ_{t-1}) of the following long-run relationships:

$$y_t = a_0 + \sum_{j=1}^{q} \gamma_j X_t + \mu_t \quad . \quad . \quad . \quad . \quad . \quad 3.6$$

$$ECM_{t-1} = \mu_{t-1} = y_{t-1} - \sum_{j=1}^{q} \gamma_j X_{t-1} \quad . \quad . \quad . \quad . \quad . \quad 3.7$$

and $\emptyset_0 < 0$ is the parameter of the error correction model ECM_{t-1} that measures the speed of adjustment from any shocks in the short-run back towards the long-run.

4.0 Result and Discussion of Findings

Descriptive Statistics

As a summary of the basic properties of the variables used in the model specification, Table 1 shows their descriptive statistics. The table show that the variables have positive mean and median values, respectively. Economic growth (GDP_P) has the highest maximum value at 379251.6, whereas, environmental pollution (CO2) has the lowest minimum value at 0.481542. In addition, the standard deviation of each variable in the model highlights the level of dispersion, and shows that CO2 has the lowest standard deviation close to the mean, while GDP_P has the largest dispersion from the mean. Moreover, the probability values of the Jarque Bera statistic at 5% level of significance suggest the non-rejection of the null hypothesis of normal distribution for all the variables except CO2.

Table 1. Preliminary Statistics of Parameters

	CO2	RURAL_PO	GDP_P	GDP_P^2
Mean	0.779027	76423581	276665.7	522.9016
Median	0.765857	76528528	284949.4	533.8065
Maximum	1.390620	1.04E+08	379251.6	615.8341
Minimum	0.481542	45967092	199311.3	446.4429
Std. Dev.	0.210454	18384077	60242.94	57.46182
Skewness	0.945443	-0.062822	0.115602	0.031873
Kurtosis	3.759672	1.686199	1.553289	1.506958
Jarque-Bera	9.170215	3.846607	4.740029	4.931734
Probability	0.010203	0.146123	0.093479	0.084935
Sum	41.28843	4.05E+09	14663282	27713.79
Sum Sq. Dev.	2.303134	1.76E+16	1.89E+11	171696.8
Observations	53	53	53	53

Source: Author's Computation, 2024.

Covariance and Correlation Matrix

Correlation and covariance matrix is a useful technique used to assess the degree and direction of relationship between variables used in the specified model. The result of the correlation matrix is highlighted as Table 2. The correlation matrix as shown in Table 2 suggest that there is negative correlation environmental pollution (CO2) and rural population (RURAL_P), and between environmental pollution (CO2) and percapita income (GDP_P). Also, a negative association is observed between CO2 and the square of economic growth (GDP^2). In addition, a positive direction of movement is found to exist between rural population (RURAL_PO) and economic growth (GDP_P), as well as between rural population (RURAL_PO) and the square of economic growth (GDP^2). Moreover, the relationship between CO2 and RURAL_PO is very significant, and negative which is a preliminary indicator of the existence of an inverse relationship between the two variables.

Table 2. Matrix of Covariance and Correlation

Covariance Correlation	CO2	RURAL_PO	GDP_P	GDP^2
CO2	0.043455 1.000000			
RURAL_PO	-2922295. -0.769833	3.32E+14 1.000000		
GDP_P	-3251.614 -0.261401	4.84E+11 0.445338	3.56E+09 1.000000	
GDP^2	-2.955505 -0.249096	4.44E+08 0.428143	3393821. 0.999254	3239.562 1.000000

Source: Author's Computations, 2024.

Unit Root Test

The result of the Augmented Dickey Fuller (ADF) test at levels and first difference is shown in Table 3 below. The ADF Test was conducted at the intercept levels. The outcome shows that the variables were all integrated at first difference, except for rural population (RURAL_P) that was integrated at levels.

Table 3: ADF Unit Root Test

TEST	*CO2*	*RURL_PO*	*GDP_PER*	*GDP^2*
ADF_I^*	-2.921175 (0.5838)	-2.919952 (0.0585)	-2.919952 (0.8144)	-2.919952 (0.7977)

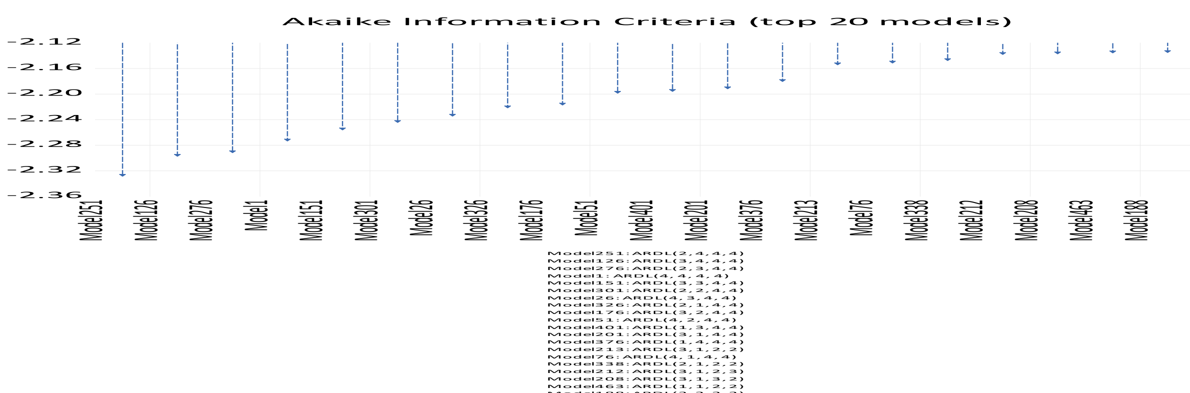
ΔADF_I^*	-2.919952	-2.919952	-2.919952	-2.921175
	(0.0000)	(0.9373)	(0.0000)	(0.0140)

Source: Author's Computation, 2024.

Analysis of Cointegration

The outcome of the ADF unit root test suggest the applicability of the ARDL bound test approach. However, before the application of the cointegration technique, it is imperative that the optimal lag length is verified. According, the result of the optimal model selection as chosen by the Akaike Information Criteria (AIC) is shown in Figure 1. The table shows that the ARDL model 2.4.4.4 is preferred and the reason is because it has the lowest value among the values of the AIC.

Figure 2 Akaike Information Model Order Selection



Upon ascertaining the preferred ARDL model, the study went further to investigate whether there is long run relationship between variables in the model using the ARDL bound test approach. The result of the bound test is found in Table 4.

Table 4. ARDL Bound Test Output

Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	4.845872	10%	2.37	3.2

K	3	5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

Source: Author's Computation, 2024.

Accordingly, the null hypothesis of the bound test proposes that there is no levels relationship existing between the variables in the model. The acceptance or rejection of the null hypothesis is based on the value of the F. statistic vis a vis the lower I(0) and upper bound I(I) values at the different levels of significance. The result shows that the F. statistic value (4.845872) is higher than the lower and upper bound values at all levels of significance, which therefore is suggestive of the existence of long run cointegration relationship between environmental pollution (CO_2), rural population, real per capita output and the square of real per-capita output during the period under study.

Long-run Estimates (ARDL 2.4.4.4 Model Output)

The signs and magnitudes of the coefficients of variables in the rural population and environmental pollution model in the long run are shown in Table 5. The outcome indicates that rural population growth has positive and statistically significant impact on air pollution in Nigeria. The sign of RURAL_P is positive and statistically significant, indicating that in the long run, a rise in total rural population by 1%, may increase air pollution by as much as 0.00000133%. Interestingly, the findings also highlight the existence of positive relationship between economic growth (GDP_P) and environmental pollution (CO_2), and shows that as GDP_P increases by 1%, the estimated rise in air pollution is 0.0026% in the long run. However, the sign of the magnitude depicting the relationship between the square of percapita income (GDP^2) and air pollution (CO_2) is negative and statistically significant at the 5% level of significance. This particular outcome indicates that for a 1% rise in percapita income, environmental pollution will decrease by 2.5% in the longrun.

Table 5 Long-run Output of ARDL Model 2.4.4.4

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
RURAL_P	0.0000000133	0.00000000155	-8.525693	0.0000

GDP_P	0.0000260	0.0000125	2.079646	0.0459
GDP^2	-0.025570	0.012904	-1.981581	0.0565
C	7.692998	3.326283	2.312791	0.0275

Source: Author's Computation, 2024.

The ECM and short run estimates of the ARDL model are shown in Table 6. The findings show that the parameters are statistically significant at various lags. The ECM is correctly signed and its value (-0.708723) indicates that about 71% of short run shock will be corrected annually. Interestingly, the table shows the mixed effects of changes in rural population (RURAL_P) and real per capita income (GDP_P) on air pollution in the short run. Precisely, the findings suggest that a 1% increase in the rural population exerts positive pressures on air pollution by as much as 0.000000379% and 0.000000220% in the first and third lags, respectively. The outcome also revealed that increase in percapita income has a mixed effect on environmental pollution in the short run. The table suggest that a 1% increase in per capita income exerts positive influence on CO2 emissions in the current period by as much 0.00152%%; but this is counteracted in the first lag and third lags, respectively. The square of economic growth (GDP^2) indicates the positive influence of increased productivity on CO2 emissions in the short run. Moreover, the table also reveals that the explanatory power of the model is above average as 77% of the variation in CO2 is explained by the independent variables employed in the model, while the Durbin Watson Statistic value (1.982737) attest to the absence of serial correlation in the estimated regression model.

Table 6. Short-Run Output (ARDL Model 2.4.4.4)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2(-1))	0.404022	0.137946	2.928844	0.0063
D(RURAL_P(-1))	0.000000379	0.000000163	2.318838	0.0272
D(RURAL_P(-2))	-0.000000417	0.000000163	-2.559504	0.0156
D(RURAL_P(-3))	0.000000220	0.000000112	1.967125	0.0582
D(GDP_P)	0.0000152	0.00000946	1.609916	0.1176
D(GDP_P(-1))	-0.0000469	0.0000101	-4.647086	0.0001

D(GDP_P(-2))	0.0000125	0.00000988	1.260208	0.2170
D(GDP_P(-3))	-0.0000418	0.00000991	-4.221392	0.0002
D(GDP^2(-1))	0.045107	0.010597	4.256608	0.0002
D(GDP^2(-3))	0.043280	0.010245	4.224566	0.0002
CointEq(-1)*	-0.708723	0.135504	-5.230271	0.0000

R-squared	0.773506	Mean dependent var	-0.011343
Adjusted R-squared	0.689380	S.D. dependent var	0.111155
S.E. of regression	0.061950	Akaike info criterion	-2.490009
Sum squared resid	0.134325	Schwarz criterion	-1.949489
Log likelihood	75.00523	Hannan-Quinn criter.	-2.284937
Durbin-Watson stat	1.982737		

Source: Author's Computation, 2024.

Post-Diagnostic Tests

Furthermore, post-estimation tests on the output of the specified model were conducted and the result is shown in Table 7 below. Table 7 highlights the result of the Breusch Godfrey (BG) Serial correlation LM test, Breusch-Pagan-Godfrey heteroscedasticity test and the Jarque Bera test for normality. The output suggests that the BG and BPG tests with the null hypothesis of no serial correlation in the residuals and no heteroscedacity cannot be rejected as their p-values are greater than the adopted 5% level of significance in both the F test and Obs.*R-Square statistic. Moreover, Figure 2 shows that the Jarque Bera test of Normality is in conformity with expectations as the J.B probability value of 0.53 is above the 5% significance level.

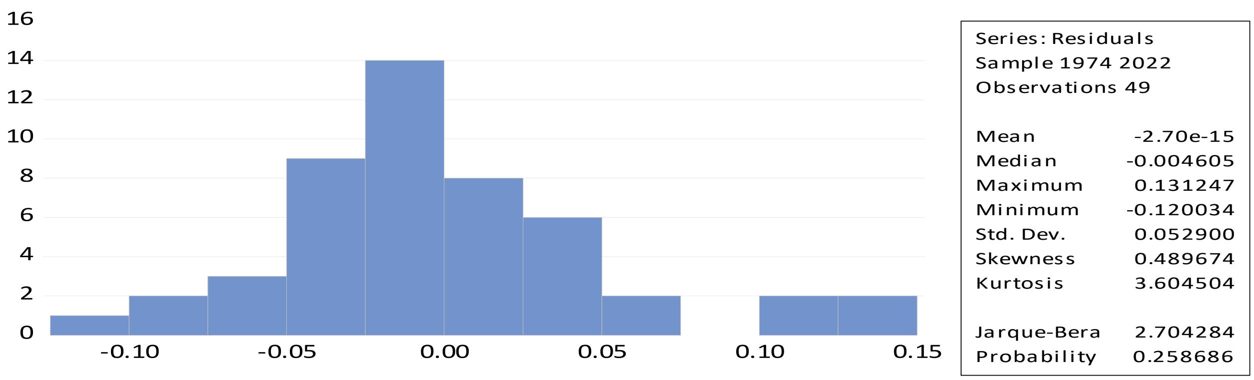
Breusch-Godfrey (LM) Test for Serial Correlation			
F-statistic	0.753933	Prob. F(2,29)	0.4795
Obs*R-squared	2.421850	Prob. Chi-Square(2)	0.2979
Breusch -Pagan-Godfrey Test for Heteroscedasticity			
F-statistic	1.022512	Prob. F(17,31)	0.4628
Obs*R-squared	17.60449	Prob. Chi-Square(17)	0.4142

Scaled explained SS	9.175920	Prob. Chi-Square(17	0.9346

Table 7. Post Estimation Diagnostic Tests Output

Source: Author's Computation, 2024.

Figure 3. Normality Chart



Stability Tests

Figure 3: CUSUM and CUSUM of Squares

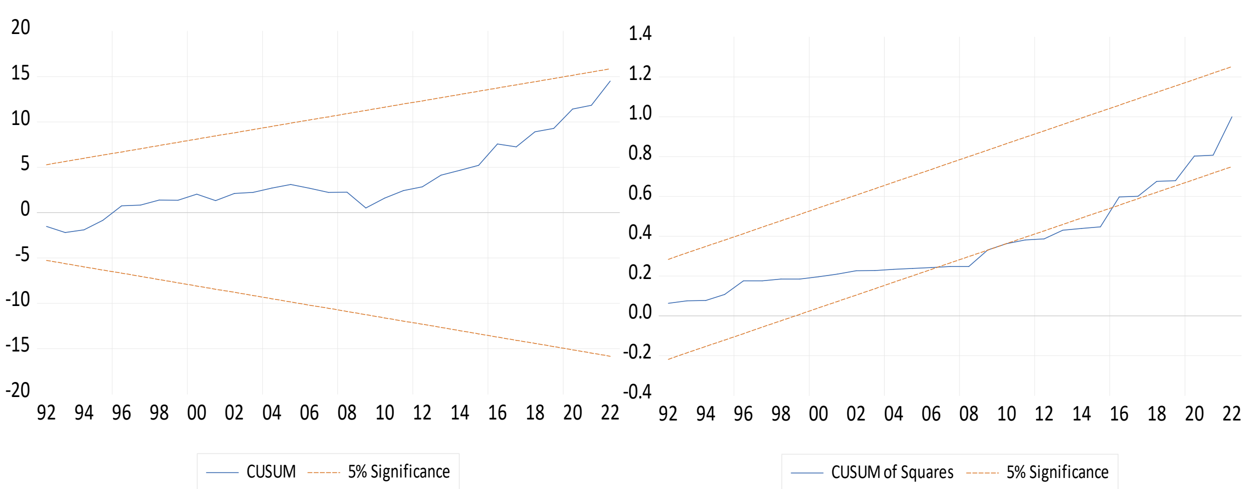


Figure 4 shows the output of the cumulative sum of squares (CUSUM) and the cumulative Squares (CUSUM of Square) tests for parameter stability. The output indicates that the CUSUM and CUSUM of Squares are located within the 5% critical values which means no structure breaks in the regression model and the parameters of the model are stable over time.

4.1 Discussion of Findings

There is evidently no gainsaying the point that human location may not stop emission of carbon dioxide, as long as it does not disrupt livelihood activities. Nonetheless, the type of economic activities and its scale as perpetuated by the population of people in rural relative to urban areas may determine the amount of carbon dioxide emissions. In this context, since industrial (high energy-intensity) and service-oriented activities are usually associated with urban population, the level of carbon emission should be relatively higher than that of rural areas where most people are engaged in the primary sector of the economy. The findings of the study therefore highlight the response of total rural population as well as real output on environmental pollution Nigeria.

The result of the ARDL bound test shows the existence of long run relationship between total rural population, economic growth and carbon dioxide emissions in Nigeria. The result of the bound test affirms the explanatory variables as determinants of CO2 emissions during the period under study. This outcome is not out of place as human activities in production and consumption could exert considerable influence on the volume of carbon emission at a point in time. Continuing, on the first objective of the study which is to determine the specific impact of rural population and economic growth on CO2 emission, the result shows that total rural population responded positively to air pollution in the short and long run time period, but its impact was relatively smaller compared to economic growth. Precisely, the result shows that total rural population exerts a positive effect of 0.0000000133% for every 1% rise in its population. This finding could be attributed to the nature of primary sector activities such as agriculture, forestry, fishing and mining carried out by people in rural communities in Nigeria. It has been suggested that indiscriminate bush burning which is a prevalent pre-farming season activity in rural communities in the country, as well as the practice of using firewood as an energy source for cooking and deforestation contributes to poor atmospheric ventilation and pollution (Emetere and Aghogho, 2019). The paper therefore rejects the null hypothesis of negative relationship between rural population and CO2 emissions in Nigeria.

The second objective of the study sought to determine the validity or otherwise of the EKC in Nigeria. Accordingly, the study findings showed the mixed influence of per capita income and it's square on CO2 emission in the short run. This outcome is indicative of the impact that the scale of production activities, as dictated by the nature of the business cycles and human development could have on the environment. The environment is often degraded through negative spillovers continually deposited on it from extractive, manufacturing and transportation activities. Even though these activities enhance the economy and generate employment, they not only stress but devalue the environmental system. However, the findings suggest that in the long run, the influence of per capita income and the square of GDP per capita on CO2 emissions is positive and negative respectively which affirms the presence of EKC in Nigeria. Precisely, the positive and negative coefficient of GDP per capita and square of GDP per capita is suggestive of an inverted U-shaped relationship between per capita income and CO2 emission in the long run. The findings therefore portend that the growth of GDP per capita will contribute less to CO2 emissions in the long-run. The paper argues that this is possible because rising economic growth when translated to improved human development could engender a better understanding of the imperative of sustaining the environment for improved welfare. Adelegan and Otu (2020) in their study of environmental quality and economic growth in Nigeria also arrived at similar conclusion. Therefore, on the basis of this finding, the study does not reject the alternate hypothesis denoting evidence of the EKC in Nigeria in the period under review.

5.0 Conclusion and Recommendations

In an effort to ensure economic prosperity, inhabitants of rural communities either engage in production and/or service-oriented activities to generate incomes and sustain their wellbeing. For many of them, these livelihood activities are bolstered through the dynamic combination of human capital and natural resources found in their immediate environment. However, even though some of this rural livelihood practices are historically rooted in antiquity and may not be out of place, the problem nevertheless is the prospect of increased carbon emissions in a world challenged by issues of climate change and environmental pollution.

The seriousness of the problem of environmental pollution is buttressed by the many global strategic agreements among developed and developing countries on the need to sustain the environment. These agreements and the goals set therein have contributed to more elaborate research on the nexus between human development, economic growth and environmental degradation. Accordingly, it is expected that in tandem with the global goal of sustainable environment across the world, the volume of carbon dioxide emissions will decline in the long run. This, in part would be due to decreased consumption of fossil fuels, and the rise in the use of fuel switching mechanical processes and devices.

Consequently, the findings of the study while they in part, point to the influence of rural population and economic growth as drivers of air pollution in Nigeria; they also stress the need for the country to reduce the air pollution by formulating sustainable policies. A critical challenge for Nigeria is sustaining the growth of national output, while evolving new energy mechanisms that would ensure seamless switch from its high intensity fossil-fuel dependent economy to renewable energy resources. The challenge is intensified by the fact that the cost of such a transition on a national scale may be quite high in a country where many of the rural population are within the low-income bracket and do not have the requisite education, and skills to adopt cleaner energy production systems, and the environmental regulatory institutions are seen as weak. However, the reverse would be the case where there is increased human development and regulatory institutions firmly discharge their responsibilities.

To this end, the paper notes that the social benefits of human development to the economy and the environment is high, and therefore recommends that the national and subnational governments in Nigeria should actively invest financial resources in advancing the human capital base of people in rural communities. This is because of the high propensity for a well-educated rural farm population to better understand and adopt measures that reduce air pollution, as well as utilise machineries and systems that require the use of cleaner energy sources in production and consumption activities and so, reduce the devaluation that is caused by the rise in economic activities on the natural environment. In addition, there is the need for more stringent control by the environmental regulatory institutions in the country. This would act to deter economic agents whose production systems engender air pollution and further help in the fight against climate change.

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