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Population Growth and CO_2 Emission in Nigeria: A Recursive ARDL Approach

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Abstract

Theoretically, population growth is believed to increase greenhouse gas emissions, particularly CO_2 emissions through the increase in human activities. Accordingly, this study aimed to investigate this assertion in Nigeria using an autoregressive distributed lag model covering periods from 1971-2000, 1971-2005, and 1971-2010 recursively. The results indicated that population was not a determinant of CO_2 emissions in all the three periods in the long run. However, economic growth was found to be the only long-run CO_2 emissions determining factor within the studied periods. However, in the short run, virtually all the explanatory variables and their lags, that is, population growth, economic growth, and energy consumption, were significant in determining CO_2 emissions. The findings suggested that population growth, which is the focal point of the study, could only determine CO_2 emissions in the short run. Therefore, population checking measures could be a short-run effective measure to lower the emissions level. Also, further research should be conducted on how to effectively and efficiently manage the population growth–CO_2 emissions relationship.

Keywords

population growth, CO_2 emissions, ARDL approach, VECM Granger causality

Introduction

It seems obvious that global warming is largely caused by greenhouse gases (GHG), predominantly from industrial, agricultural, and transportation activities. CO_2 emissions are the main contributor to the total GHG emissions (Intergovernmental Panel on Climate Change, 2015). The GHG are composed of more than 60% CO_2 (Kaygusuz, 2009). In addition, Yunfeng and Laike (2010) reported that CO_2 emissions are responsible for 72% of the global warming effects. One of these major effects is that it results in a rise in temperature, which in turn causes a rise in sea level from thermal expansion of the water. Equally, rising temperature means a rising sea level through the addition of melt water to the sea from melting glaciers, which poses a great threat socially and economically. This rise in sea level causes increasing coastal erosion, flooding, property damage, and potential loss of lives in low-lying coastal countries such as Nigeria.

In recent times, many countries aspire for higher economic growth through implementation of some targeted plan that requires higher energy consumption for industrial production. As such, energy plays a crucial role in the economic growth of all countries. Mulugeta, Nondo, Schaeffer, and Gebremedhin (2010) asserted that energy use is an essential driver in economic growth based on an economic growth hypothesis, which directly or indirectly supports labor and capital as an input factor in production. The quest for growth makes many nations to increase their energy consumption to meet their productive capacity. At the same time, increased energy consumption is attributed to increased emissions intuitively and as empirically reported by Ang (2008), Ozturk and Acaravci (2010), Park and Hong (2013), Hossain (2014), and Begum, Sohag, Abdullah, and Jaafar (2015).

Nigeria embarked on diversification of the economy since 1960 after its independence with growing industrial, manufacturing, agricultural, financial, and tourist sectors. These sectors require a strong reliance on fossil fuels for their energy needs. The upsurge in use of fossil fuels for energy generation facilitates CO_2 emissions in the country. Besides fossil fuel consumption, human activities such as destruction of forests (deforestation), bush burning, ranching, and building are believed to be increasing GHG constantly in the atmosphere.

In most cases, CO_2 emission is linked to anthropogenic activities and that is the emission that is worrisome. On the contrary, anthropogenic activities increase with an increase or growth in human population, thus leading to rise in CO_2

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emissions. Liddle (2015) asserts that over the next decades, increase in population can increase energy use and thus causing rise in CO_2 emissions. Nigeria is the most populous country in Africa with population of 186 million people. Equally, the country has the fastest growing population on the Africa's continent with 2.6% annual growth rate in 2016. The country is ranked 44th emitter in the list of over 200 World's countries. However, with the pace at which the country's population is growing, the concern for increase in CO_2 emissions, which accompany it, equally grows. As such, it is likely that the country's per capita emissions will continue to rise due to the fast population growth. This will expectedly increase the cumulative CO_2 emissions significantly. Therefore, Nigeria is expected to devise sustainable ways of addressing CO_2 emissions.

Climate change is not just an environmental issue any longer; it has become a development issue when looking at its potential impact on the economic activities. It poses a serious threat to sustainable development of many developing countries, particularly Nigeria. For instance, it is projected that climate change may result in a loss of 6% to 30% in Nigeria's GDP by 2050, which translates to US$100 billion to US$460 billion if no adaptation measures are taken (Department for International Development, 2009). That study further predicted that the country may suffer a loss of 2% to 11% in GDP by 2020 if the current trend is maintained.

The significance of this study cannot be overemphasized. First, it should help to inform decision makers on the determinants of CO_2 emissions. Second, it provides policy recommendations that could assist in tackling the emissions, while maintaining long-run economic growth and averting the potential loss in GDP in the future. Equally, the empirical findings could further provide a hint on how CO_2 emissions responded to its determinants over the studied period.

The objective of this study was to look at the effects of population growth along with energy consumption and economic growth on CO_2 emissions in Nigeria. Many studies conducted in Nigeria only looked at either the effect of energy consumption alone on CO_2 emissions or the effects of energy consumption and economic growth on CO_2 emissions. Therefore, this is the gap that the study intended to fill in the literature. According to theory, population growth is supposed to have a direct relationship with CO_2 emissions because an increase in population means an increase in human activities that facilitate CO_2 emissions, but only empirical tests could validate this. Accordingly, this study sought to empirically test the effects of population growth, economic growth, and energy consumption on CO_2 emissions in Nigeria by employing an autoregressive distributed lag (ARDL) model advanced by Pesaran, Shin, and Smith (2001) in a recursive form. Dividing the sample size recursively allowed capture of the different growth rates of population in the three periods (1971-2000, 1971-2005 and 1971-2010) and how the CO_2 emissions reacted in these periods. It also enabled capturing the real behavior of all the variables in different periods. The results of the analysis further revealed whether or not the response of the CO_2 emissions to population growth was the same in all the periods.

This article is organized in sections. The first section contains introduction, research problem, significance of the study, objective and organization of the article. The second section consists of review of related literature, which provides some snapshots of similar empirical literature. The third section presents methodology and data. The fourth section presents results and discussion of the article. Finally, the fifth discusses conclusions and policy recommendations.

Review of Related Literature

Many research studies have been conducted in areas related to this study. However, a major part of the researches conducted were either on an energy consumption–growth nexus or on an energy consumption–CO_2 emissions–growth nexus. Review of literature shows that there are no many existing studies that specifically examine the effect of population growth on CO_2 emissions, especially on Nigeria. Though there is a bunch of literature that investigated the relationship between energy consumption, CO_2 emissions, and economic growth, the literature review here will give an overview of the existing literature on the related topic from general perspective and later narrow it down to focus on Nigeria. In other words, the literature review will be twofold. The first strand of the literature review focuses on the general review of related existing studies, whereas the second strand focuses specifically on the review of related existing studies focusing on Nigeria.

Starting with the first strand, Kraft and Kraft (1978) pioneered the investigation of the relationship between energy use and income. Kraft and Kraft's (1978) study was conducted using United States' data covering 1947 to 1974 period. Ever since the publication of this study, several empirical studies surfaced with different methodologies and varying sample size to examine relationship and/or causality between energy use, trade openness, economic growth, population density, and CO_2 emissions, in different countries and regions of the World. Some of these studies include Acaravci and Ozturk (2010); Menyah and Wolde-Rufael (2010); Lotfalipour, Falahi, and Ashena (2010); Alam, Begum, Buysse, Rahman, and Van Huylenbroeck (2011); Arouri, Youssef, M'henni, and Rault (2012); Alam, Begum, Buysse, and Van Huylenbroeck (2012); Alkhathlan and Javid (2013); Khan, Khan, Zaman, Khan, and Zahoor (2013); Sulaiman (2014); Chindo, Abdulrahim, Waziri, Huong, and Ahmad (2015); Ohlan (2015); Manu and Sulaiman (2017); and Sulaiman and Abdul-Rahim (2017).

For instance, Acaravci and Ozturk (2010) examined the causality between energy use, economic growth, and CO_2 emissions in some selected 19 European countries, covering 1960 to 2005 period. Applying autoregressive distributed lag

(ARDL) approach and error-correction Granger causality test, the study only found an evidence of long-run relationship between real GDP, energy use, and CO_2 emissions in Germany, Switzerland, Italy, Denmark, Iceland, Portugal, and Greece. A unidirectional causality was equally present in these countries. In a similar empirical investigation, but for a single country, Menyah and Wolde-Rufael (2010) investigated the causality between energy consumption, pollutant emissions, and economic growth in South Africa covering the 1995-2006 period. After applying ARDL approach bounds test, the study revealed a long-run relationship between the variables and indicated unidirectional causality running from pollutant emissions and energy consumption to economic growth, and from energy consumption to pollutant emissions. Using Toda-Yamamoto procedure of causality test to examine causal relation between economic growth, CO_2 emissions, and fossil fuels, Lotfalipour et al. (2010) showed a unidirectional causality running from energy consumption and GDP to CO_2 emissions in Iran. The study further revealed the economic growth is neither caused by energy consumption nor CO_2 emissions. A long-run bidirectional causality between CO_2 emissions and energy consumption was reported by Alam et al. (2011) for India. The study further indicated that there exist no causality between energy consumption and income. Also, absence of causality between CO_2 emissions and economic growth was reported. On a panel study front, Arouri et al. (2012) examined the relationship between CO_2 emissions, energy consumption, and real GDP in 12 middle east and north African countries (MENA) covering the 1981-2005 period. The study, which applied bootstrap panel method, found that energy consumption has significant positive impact on CO_2 emissions. Analyzing the relationship between CO_2 emissions, energy consumption, and economic growth at both aggregate and disaggregate levels in Saudi Arabia between 1980 and 2011 period, Alkhathlan and Javid (2013) indicated that CO_2 emissions increase with an increase in per capita income. On the contrary, covering 1975 to 2011 period, Khan et al. (2013) disclosed that energy consumption significantly cause CO_2 emissions in Pakistan.

Furthermore, Ohlan (2015) investigated the impact of population density, energy consumption, trade openness, and economic growth on CO_2 emissions in India over the 1970-2013 period. Using ARDL approach, the study revealed that population density, economic growth, and energy consumption have significant positive impact on CO_2 emissions in both long-and short-run. However, population has been revealed to be the main contributing factor to CO_2 emissions in India. Applying same ARDL method, Sulaiman and Abdul-Rahim (2017) examined the three-way linkage relationship between CO_2 emissions, energy consumption, and economic growth in Malaysia over the 1975-2015 period. The results of the study indicated that economic growth is influenced neither by energy consumption nor by CO_2 emissions. However, CO_2 emissions is revealed to increase with an increase in both energy consumption and economic growth. In similar vein, using the simple ordinary least squares (OLS) method, Manu and Sulaiman (2017) analyzed the relationship between energy consumption, CO_2 emissions, and economic growth in Malaysia. The findings of the study that covers the 1965-2015 period revealed that CO_2 emissions decreases with an increase in income and increase with an increase in trade openness and that environment Kuznets curve is nonexistent.

The second strand of the literature review focuses on the studies which investigated the relationship between economic growth, energy consumption, and CO_2 emissions in Nigeria. The bulk of these researches could be grouped into two categories. The first category of research related energy consumption with growth without explicitly considering the role of other potential determinants. For instance, Dantama, Abdullahi, and Inuwa (2012) opined that energy consumption in the form of petroleum and electricity consumption promotes economic growth in Nigeria, even as coal consumption was found to be insignificant in promoting growth. Similarly, a bidirectional causal relationship was stated to have existed between energy consumption and economic growth in Nigeria in the long run with no evidence of the environmental Kuznets curve (EKC; Essien, 2010). Adopting the Granger causality test, Adeniran (2009) maintained that unidirectional causality runs from GDP to electricity consumption, and so GDP causes gas consumption but with absence of causality between oil consumption and GDP. To sum up, Adeniran (2009) concluded that energy consumption causes economic growth in Nigeria. More so, the Granger causal relationship between energy consumption and economic growth has been reported positive by many other studies (Odularu & Okonkwo, 2009; Olusegun, 2008; Omotor, 2008). In summary, the relationship between energy consumption and economic growth in Nigeria could be adjudged to be positive based on the previous literature.

The second bloc of literature relates energy consumption with CO_2 emissions and economic growth or GDP. This literature was focused more on how and whether there is a causal relationship between energy consumption, CO_2 emissions, and economic growth. For example, Akpan and Akpan (2012) showed that economic growth is associated with increased carbon emissions, which are accelerated by electricity consumption. As such, they concluded that Nigeria's growth process is pollution intensive and evidence of the EKC does not exist. Upholding this argument, Nnaji, Chukwu, and Nnaji (2013) affirmed that economic growth in Nigeria could not be unconnected with an increase in CO_2 emissions and that emissions are facilitated by fossil fuel consumption. This finding is more practical as electricity supply in Nigeria has witnessed a drastic drop over the years that made the economy rely more on alternative sources of energy, specifically fossil fuel. Recently, Chindo et al. (2015) based on ARDL divulged that GDP growth is an increasing function of CO_2 emissions in Nigeria after establishing a positive relationship between the duo. Furthermore, applying the Toda and Yamamoto causality test, Sulaiman (2014) revealed that CO_2 emissions facilitate growth, energy consumption increases CO_2 emissions, and that there exists two-way causality between energy consumption and growth in Nigeria.

Conclusively, all the relevant literature on Nigeria in this area generally focused on relating energy consumption, pollutant emissions, and economic growth or GDP. Nonetheless, human activities such as bush burning, ranching, deforestation, and other human activities are believed to aid GHG emissions, principally the CO_2 component. These activities are assumed to further increase with population growth. This is because as population rises, human activities are also expected to rise. In line with this, this study seeks to fill this gap by testing the impact of population growth on CO_2 emissions.

Methodology and Data

The Nigeria's annual data employed by this study spans from 1970 to 2010 in recursive form. The data were sourced from World Development Indicators of World Bank. CO_2 emissions, CO_2 (in metric tons per capita), is modeled as a dependent variable, while energy consumption, EC (fossil fuel per capita), economic growth, Y (real GDP per capita), and population growth rate, PG, are the independent variables. The summary of the variables' names, sources, measurements, and expected signs is shown in Table A1 (see Appendix A). Other previous research made use of proxies such as electricity consumption and nuclear power to measure energy consumption. However, the rationale behind choosing fossil fuel consumption to proxy energy consumption is because the Nigerian economy basically runs on fossil fuel consumption (the major source of energy) as electricity supply has been unreliable if not inadequate. At the same time, nuclear power has not been fully developed yet in the country. Therefore, fossil fuel consumption is the reliable measure of energy consumption in the Nigerian case.

Moreover, the sample periods have been divided into three clusters in a recursive format. The whole of observations were grouped recursively as follows: 1971-2000, 1971-2005, and 1971-2010. This was done to see whether there existed any difference in the behavior of the variables in these three periods. Therefore, three similar models were used at every step for the respective periods.

To derive the model, it is known that based on theory, CO_2 emissions are assumed to be a function of income (economic growth). In other words, CO_2 is released from economic activities. Therefore, the relationship can be denoted as follows:

$$CO_2 = h\big(f(Y)\big),$$

where $Y = f(K, L)$, a production function model (i.e., traditional production function) with K and L defined as capital and labor, respectively, and h denotes the rate of emissions from the production function.

To specify the model, it is worthy of note that Stern (2004) pointed out that most of the EKC literature is econometrically weak. Narayan and Narayan (2010) concurred with this view by stating that modeling emissions as a function of income and income-squared and/or income-cubed in a single model may lead to a collinearity problem or multicollinearity between income and income-squared, and between income-squared and income-cubed. This assertion was subsequently proved in their work and as such, they concluded that a linear relationship between emissions and income is more appropriate econometrically. This argument was further buttressed by Alkhathlan and Javid (2013) who employed a standard log-linear functional relationship between carbon emissions as a dependent variable and income and energy consumption as independent variables to avoid multicollinearity and variable bias. Following these authors, this study specified its model in a simple log-linear form and augmented it with population growth variable as follows:

$$CO_{2t} = \delta_0 + \delta_1 Y_t + \delta_2 EC_t + \delta_3 PG_t + \eta_t, \qquad (1)$$

where CO_{2t} stand in for CO_2 emissions per capita, Y_t is real GDP per capita, EC_t is energy consumption per capita, PG_t is population growth rate, and η_t is a disturbance term.

The cointegration approach of the ARDL model has been employed in a recursive format to test for cointegration relationships between the variables of interest. Despite that there are other methods for achieving the same purpose, this approach has several advantages:

1. The approach is applicable regardless of the order of integration of the variables in a model (i.e., whether they are I[0], I(1) or mixed);
2. With ARDL, both short- and long-run coefficients can be simultaneously gotten;
3. It captures both short- and long-run dynamics while testing cointegration relationships; and
4. It is a good and preferred approach for small time series samples (30-80) and a finite sample.

Resting upon these advantages, this study chose this approach and formulated the conditional error correction model as:

$$\begin{aligned}\Delta \ln CO_t = {} & \alpha_0 + \sum_{i=1}^{m} \psi_i \Delta \ln CO_{t-i} + \sum_{i=0}^{m} \chi_i \Delta \ln Y_{t-i} + \\ & \sum_{i=0}^{m} \beta_i \Delta \ln EC_{t-i} + \sum_{i=0}^{m} \varphi_i \Delta PG_{t-i} + \phi_1 \ln CO_{t-1} + \\ & \phi_2 \ln Y_{t-1} + \phi_3 \ln EC_{t-1} + \phi_4 PG_{t-1} + \omega_t.\end{aligned} \qquad (2)$$

Equation 2 is estimated using the OLS method to test for cointegration relationships among CO_2 emissions, economic growth, energy consumption, and population growth by conducting a Wald test/F-test to ascertain the joint significance of the lagged coefficients of the variables. To accomplish this task, the null hypothesis of no cointegration in Equation 2 is defined as $H_o : \phi_1 = \phi_2 = \phi_3 = \phi_4 = 0$, as against the alternative hypothesis, which states that cointegration exists ($H_o : \phi_1 \neq \phi_2 \neq \phi_3 \neq \phi_4 \neq 0$). To decide on the result, Pesaran et al. (2001) recommended that the calculated F-statistic should be compared with the upper and lower bounds of the critical values. If the F-statistic exceeds the upper bound, cointegration exists. If the F-statistic lies in between the lower and upper bounds, the test result is said to be inconclusive. However, if the F-statistic lies below the lower bound, then no cointegration exists among the variables. If cointegration is established among the variables, the long-run and short-run models of ARDL specification in Equations 3 and 4 are then estimated, respectively.

$$\ln CO_t = \alpha_0 + \sum_{i=1}^{m} \psi_{1i} \ln CO_{t-i} + \sum_{i=0}^{m} \chi_{1i} \ln Y_{t-i} + \sum_{i=0}^{m} \beta_{1i} \ln EC_{t-i} + \sum_{i=0}^{m} \varphi_{1i} PG_{t-i} + \omega_{1t}, \quad (3)$$

$$\Delta \ln CO_t = \alpha_0 + \sum_{i=1}^{m} \psi_{2i} \Delta \ln CO_{t-i} + \sum_{i=0}^{m} \chi_{2i} \Delta \ln Y_{t-i} + \sum_{i=0}^{m} \beta_{2i} \Delta \ln EC_{t-i} + \sum_{i=0}^{m} \varphi_{2i} \Delta PG_{t-i} + \theta ECT_{t-1} + \omega_{2t}, \quad (4)$$

where the coefficient of the error correction term (ECT) is denoted by θ that shows the speed of adjustment of the variables toward long-run convergence.

Last, this study diagnosed the model by conducting tests for serial correlation, heteroscedasticity, normality, and functional form. In addition, the study heeded the suggestion by Pesaran and Pesaran (1997) by conducting cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) to assess how stable the model is along the sampled periods.

Robustness Check Using Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS)

To gauge the long-run estimates, we apply DOLS and FMOLS. DOLS and FMOLS have the power to deal with endogeneity and small sample bias. These estimators are good for robustness check of ARDL estimates. DOLS and FMOLS have been advanced by Stock and Watson (1993) and Phillips and Moon (1999), respectively, to address the problems of serial correlation and small sample bias attributed to OLS estimator. The estimators can also be applied to mix order of integrated variables in cointegration framework. Considering the strengths of these estimators, their results will serve as robustness checks to ARDL results.

Vector Error Correction Model (VECM) Granger Causality

Having found cointegration between the variables, the direction of causation between the variables is examined using VECM. Sulaiman and Abdul-Rahim (2017) and Shahbaz, Hye, Tiwari, and Leitão (2013) maintained that VECM is suitable for analyzing causality between variables of interest when the variables are cointegrated. Equally, the methodology is suitable for estimating causality between variables of the same order, that is, when they are integrated of order one. The VECM modeling framework within a system of error correction model for this study is as follows:

$$\begin{bmatrix} \Delta \ln CO_{2t} \\ \Delta \ln Y_t \\ \Delta \ln EC_t \\ \Delta PG_t \end{bmatrix} = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} + \begin{bmatrix} d_{11m} & d_{12m} & d_{13m} & d_{14m} \\ d_{21m} & d_{22m} & d_{23m} & d_{24m} \\ d_{31m} & d_{32m} & d_{33m} & d_{34m} \\ d_{41m} & d_{42m} & d_{43m} & d_{44m} \end{bmatrix} \times \begin{bmatrix} \Delta \ln CO_{2t-1} \\ \Delta \ln Y_{t-1} \\ \Delta \ln EC_{t-1} \\ \Delta PG_{t-1} \end{bmatrix} + \cdots + \quad (5)$$

$$\begin{bmatrix} d_{11n} & d_{12n} & d_{13n} & d_{14n} \\ d_{21n} & d_{22n} & d_{23n} & d_{24n} \\ d_{31n} & d_{32n} & d_{33n} & d_{34n} \\ d_{41n} & d_{42n} & d_{43n} & d_{44n} \end{bmatrix} \times \begin{bmatrix} \Delta \ln CO_{2t-1} \\ \Delta \ln Y_{t-1} \\ \Delta \ln EC_{t-1} \\ \Delta PG_{t-1} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} (ECM_{t-1}) + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix},$$

where the error correction terms' coefficients are represented by $\lambda_1 - \lambda_4$, the homoscedastic disturbance terms are denoted by $\varepsilon_{1t} - \varepsilon_{4t}$, the error correction term is denoted by ECM_{t-1}. The ECM_{t-1} indicates both long-run causality and the speed of adjustment to long-run equilibrium, while the Wald test statistic of the first-differences of the variables shows the short-run causality and its direction.

Results and Discussion

To begin the estimation, the time series properties of the data were first tested using augmented Dickey Fuller (ADF; 1981) and Phillips Perron (PP; 1988) test statistics. Though to apply ARDL it is not necessary to check the order of integration of the variables, the study conducted the unit root test to ensure that none of the variables exceeded I(1) and also to establish the appropriateness of applying the methodology. This is owing to the fact that the methodology of ARDL had been developed by Pesaran et al. (2001) based on the assumption that all the variables are either purely I(0), I(1), or mixed. Any presence of the I(2) variable would render the methodology invalid in any case. As such, this study conducted these tests and the results are

Table 1. Unit Root Test Using Augmented Dickey Fuller (ADF) and Phillips Perron (PP).

	Level				First difference				
	ADF		PP		ADF		PP		
Variables	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend	Interpretation
$\ln Y_t$	−0.79 (0.81)	−0.96 (0.937)	−1.21 (0.659)	−1.391 (0.848)	−4.96*** (0.002)	−4.92*** (0.002)	−4.93*** (0.000)	−4.88*** (0.001)	I(1)
PG_t	−7.34*** (0.000)	−4.78*** (0.003)	−4.87*** (0.000)	−3.49* (0.053)	—	—	—	—	I(0)
$\ln CO_t$	−1.97 (0.292)	−2.538 (0.309)	−1.99 (0.289)	−2.54 (0.309)	−6.78*** (0.000)	−6.68*** (0.000)	−6.89*** (0.000)	−6.74*** (0.000)	I(1)
$\ln EC_t$	−4.92*** (0.000)	−3.29* (0.081)	−4.88*** (0.000)	−3.49* (0.053)	—	—	—	—	I(0)

Table 2. Unit Root Test Results Based on Zivot-Andrews.

	Level				First difference				
Variables	Constant	Break point	Constant & trend	Break point	Constant	Break point	Constant & trend	Break point	Inference
$\ln Y_t$	−2.852 (2)	2004	−3.840 (2)	1998	−5.064 (1)**	1982	−5.125 (1)**	1982	I(1)
PG_t	−3.432 (4)	1989	−4.995 (4)	1998	−7.436(4)***	1989	−6.923 (4)***	2002	I(1)
$\ln CO_{2t}$	−4.093(0)	2000	−4.758 (0)	2000	−8.125(0)***	1996	−8.454 (0)***	2000	I(1)
$\ln EC_t$	−3.673 (0)	1993	−4.086 (0)	1979	−6.463(0)***	1996	−6.632 (0)***	1996	I(1)

Note. $\ln Y_t$ is natural logarithm of real GDP per capita (economic growth), PG_t is the population growth, $\ln EC_t$ is the natural logarithm of energy consumption, and $\ln CO_{2t}$ is the natural logarithm of CO_2 emission, while values in parenthesis are lag lengths.
*** and ** are significant levels at 1% and 5%, respectively.

presented in Table 1. Both ADF and PP results reveal that population growth (*PG*) and energy consumption (ln*EC*) are stationary at level, that is, I (0), while economic growth (ln*Y*) and energy consumption (ln*CO*) are stationary at first difference, that is, I (1). Therefore, considering the mix order of integration of the variables, the ARDL approach is the most fitted methodology rather than the standard or conventional cointegration approaches. However, sometimes, ADF and PP tests may not produce reliable estimates if there is a presence of structural break in the series and as such they could produce a biased result. To avoid doubt, we have equally employed Zivot-Andrews (1992) structural break trended unit root test. Table 2 shows the results of Zivot-Andrews unit root test, which reveal that all the variables are nonstationary in their level form but are stationary in first difference form. This indicates that all the variables are integrated of order one, i.e., I (1). The result of the Zivot-Andrews test also supports the application of ARDL approach.

Before testing the cointegration relationship among the variables using Equation 2, it was paramount to identify the optimum lag length to be used. However, because Equation 2 is based on the assumption that the error term, ω_t, is serially independent, it is imperative to balance between choosing the lag length, m, sufficiently large to abate the residual serial correlation problems and adequately small to avert being overparameterized, especially in view of the limited time series data (Pesaran et al., 2001, p. 308). For this reason, this study used the Schwarz information criterion (SIC) to identify the optimum lag length as shown in Table 3, which suggested lag 3 for all the periods, that is, 1971-2000, 1971-2005, and 1971-2010.

Having identified the optimum lag length, the next step was to estimate the long-run relationship among the variables by OLS. The null hypothesis of no cointegration ($H_o: \phi_1 = \phi_2 = \phi_3 = \phi_4 = 0$) was tested against the alternative of the existence of a cointegration relationship ($H_o: \phi_1 \neq \phi_2 \neq \phi_3 \neq \phi_4 \neq 0$). The result of this test presented in Table 4 indicated that the null hypothesis could not be accepted for periods 1971-2000, 1971-2005, and 1971-2010, at 5%, 1%, and 1% level of significance, respectively. The F-statistics (5.309, 7.189, 8.979) exceeded the respective upper bounds (5.018, 6.845, 6.610) of the critical values tabulated by Narayan (2005) at the aforementioned levels of significance. As such, a cointegration relationship exists in all cases.

After establishing a cointegration relationship among the variables, the long-run model in Equation 3 was estimated to

Table 3. Optimal Lag Length Selection Based on Schwarz Information Criterion (SIC) for Cointegration Test.

Lag	LogL	LR	FPE	AIC	SC
Model 1 (1971-2000)					
0	33.593	NA	8.285	−2.118	−1.878
1	158.721	194.645	5.163	−9.535	−8.095
2	228.772	83.023[a]	1.278	−12.872	−10.232
3	274.779	37.488	9.099[a]	−14.428	−10.589[a]
4	395.033	71.306	3.214	−15.019[a]	−10.231
Model 2 (1971-2005)					
0	47.136	NA	4.548	−2.718	−2.487
1	170.316	198.679	8.267	−9.053	−7.665
2	238.151	87.529	5.976[a]	−11.816	−9.639
3	286.757	47.038	3.923[a]	−13.339	−9.872[a]
4	350.916	41.393[a]	3.859	−15.866[a]	−8.009
Model 3 (1971-2010)					
0	41.137	NA	9.243	−2.008	−1.788
1	179.675	230.895	1.712	−8.315	−6.996
2	265.633	119.387	6.305	−11.702	−9.092
3	306.005	45.958[a]	3.208[a]	−12.612	−9.283[a]
4	349.465	35.392	2.027	−13.581[a]	−8.963

Note. LR = sequential modified LR test statistic; FPE = final prediction error; AIC = Akaike information criterion; SC = Schwarz information criterion; LogL = log likelihood; LR = likelihood ratio.
[a]Indicates the lag suggested by each criterion.

Table 4. Bounds Test Results.

				Bounds test critical values	
				[Unrestricted intercept & no trend]	
Model	*F*-stats (*p* value)	Lag	Level of significance	I(0)	I(1)
1970-2000					
$F(\ln CO_{2t}\|PG_t,\ln ECt,\ln Y,\ln Y_t)$[a]	5.309[a] (.018)	3	1%	5.333[a]	7.063[a]
			5%	**3.710**[a]	**5.018**[a]
			10%	3.008[a]	4.150[a]
1970-2005					
$F(\ln CO_{2t}\|PG_t,\ln ECt,\ln Y,\ln Y_t)$[b]	7.189[b] (.002)	3	1%	**5.198**[b]	**6.845**[b]
			5%	3.615[b]	4.913[b]
			10%	2.958[b]	4.100[b]
1970-2010					
$F(\ln CO_{2t}\|PG_t,\ln ECt,\ln Y,\ln Y_t)$[c]	8.979[c] (.000)	2	1%	**5.018**[c]	**6.610**[c]
			5%	3.548[c]	4.803[c]
n = 30[a],35[b],40[c]			10%	2.933[c]	4.020[c]

Note. The critical bound values are obtained from Narayan (2005) table case III. Superscripts a, b, and c indicate Models 1, 2, and 3, respectively. Boldface values show the significance level and bounds at which cointegration existed.

obtain the long-run coefficients as reported in Table 5. The results revealed that for Model 1, that is, 1971-2000, economic growth is positive and significant at 10% level in determining CO_2 emissions. Precisely, a 1% increase in economic growth will lead to a 0.657% increase in CO_2 emissions. Population growth, though having positive sign, is insignificant in determining CO_2 emissions. This suggests that population growth was not responsible for an increase in the emissions within this period. Also, energy consumption exhibits a negative sign but is statistically insignificant in

Table 5. Estimated Long Run Coefficients Based on Schwarz Bayesian Criterion (SBC).

Dependent variable, lnCO_{2t}: Regressors	Coefficients	T-ratio (p value)
Model 1 (1970-2000)		
lnY_t	0.657	2.060* (.055)
lnEC_t	−0.192	−0.386 (.705)
PG_t	3.669	1.402 (.179)
Constant	0.475	0.189 (.852)
Model 2 (1970-2005)		
lnY_t	0.761	2.852*** (.009)
lnEC_t	−0.063	−0.143 (.888)
PG_t	4.185	1.746 (.095)
Constant	0.944	0.422 (.726)
Model 3 (1970-2010)		
lnY_t	0.621	3.272*** (.003)
lnEC_t	0.074	0.220 (.827)
PG_t	3.146	1.567 (.130)
Constant	1.485	0.876 (.389)

***, **, and * are significant at 1%, 5%, and 10% levels, respectively.

influencing the emissions. For Model 2, that is 1971-2005, economic growth was found to be positive and significant in affecting CO_2 emissions. Population growth shows a positive sign but is insignificant in determining CO_2 emissions within the period. The result is in line with the findings of Model 1. Still, energy consumption exhibits a negative sign but is insignificant. Last, Model 3's long-run results show that economic growth is positive and significant in determining CO_2 emissions in 1971-2010 period. Population growth and energy consumption are positive but are insignificant in affecting the emissions.

In general, what could be observed from all three long-run model estimates is that economic growth remains the main determinant of CO_2 emissions in Nigeria within the studied periods. This positive relationship between economic growth and CO_2 emissions could be supported by a number of literature studies written on (Akpan & Akpan, 2012; Chindo et al., 2015; Nnaji et al., 2013). The findings also substantiate the results of Menyah and Wolde-Rufael (2010) for South Africa and Alkhathlan and Javid (2013) for Saudi Arabia. Conversely, the findings contradicted the results in some earlier literature that argued higher national income does not necessarily lead to an increase in pollutant emissions (e.g., Brock & Taylor, 2005; Dinda & Coondoo, 2006; Jalil & Mahmud, 2009; Managi & Jena, 2008). Practically, the positive relationship between these variables may not be unconnected with the pace at which Nigeria is developing, as the economy is basically relying on oil production and exportation and a growing industrial sector, which ultimately cannot do without emissions. Recently, Nigeria has been maintaining a steady growth level at 6% for the past decade and even aspires to increase that rate in the future. In trying to maintain and even improve the rate, more industries, particularly manufacturing, have been set up, the transport sector has been improved and the communications and information technology (IT) sector has also significantly improved among others. All these sectors basically are important sources of growth and at the same time are high emitting sources. Moreover, they are all reliant on burning fossil fuel for energy generation as the electricity supply has been erratic. Therefore, intuitively, the result is quite consistent with what is obtainable in reality.

For the coefficient of population growth, which is positive but not significant in all three models, it indicates that over the studied periods, population was not one of the main determinants of emissions in Nigeria. The result may sound counterintuitive as CO_2 emissions are expected to increase as population increases through the rise in human activities. However, the results confirmed the previous study by Begum et al. (2015) for Malaysia. This can be as a result the fact that a quite significant portion of the population does not take part in any economic activities due to high unemployment rate in Nigeria, which rose through years to 14.2% in fourth quarter of 2016. The high unemployment is persistent among the youths, who are considered the able-bodied and economically active population. Similarly, energy consumption is negative for Models 1 and 2 and positive for Model 3. But all of this is insignificant in explaining the variations in the CO_2 emissions, which confirmed the results obtained by Chindo et al. (2015) for Nigeria.

The short-run results from the estimations of Equation 4 are reported in Table 6. For Model 1 (1971-2000), economic growth and its lags are all positive and significant in explaining CO_2 emissions. In addition, lagged-one of energy consumption has been found to be positively and significantly determining CO_2 emissions. The error correction term (−0.392) satisfied the econometric requirement as it is negative and significant, which shows that the feedback mechanism is working. For Model 2 (1971-2005), the results reveal that economic growth and its lags, lagged-one of energy consumption and population growth are all positive and significant in influencing CO_2 emissions. The error correction term (−0.368) is negative and significant as required. For Model 3 (1971-2010), the results indicate that the lagged-two of CO_2 emissions, economic growth and its lags, energy consumption and its lag, and population growth are all positive and significant in stimulating CO_2 emissions. The error correction model satisfies the theoretical requirement, that is, being negative and significant. To recap everything, in the short run, virtually all the variables (economic growth, energy consumption, and population growth) were significant determinants of CO_2 emissions in Nigeria. The results suggest that as economic growth, energy consumption, and population growth rise, so also will the CO_2 emissions in the short run. To show the goodness of fit of the models, R-squared, DW-statistic, Schwarz Bayesian criterion and F-statistics were all reported for each model in Table 6 and they all suggested that the three models were good fitted.

Table 6. The Estimated Short-Run Coefficients Based on Schwarz Bayesian Criterion (SBC).

Dependent variable, $\Delta \ln CO_{2t}$: Regressors	Coefficients	T-ratio (p value)
Model 1 (1970-2000)		
$\Delta \ln Y_t$	0.441	2.174** (.042)
$\Delta \ln Y_{t-1}$	0.397	1.979* (.062)
$\Delta \ln Y_{t-2}$	0.708	3.644*** (.002)
$\Delta \ln EC_t$	0.574	1.004 (.328)
$\Delta \ln EC_{t-1}$	2.197	4.372*** (.000)
ΔPG_t	1.439	1.744 (.097)
Constant	0.186	0.186 (.854)
ECM(−1)	−0.392	−3.236*** (.004)
ecm = $\ln CO_2$ – 0.657 × $\ln Y$ – 0.192 × $\ln EC$ – 3.669 × PG – 0.475 × Constant		
R^2: .688, DW-statistic: 2.087, Schwarz Bayesian Criterion (SBC): 1.746, F-stat.: 5.346*** (0.002)		
Model 2 (1970-2005)		
$\Delta \ln Y_t$	0.518	3.439*** (.002)
$\Delta \ln Y_{t-1}$	0.358	2.200** (.038)
$\Delta \ln Y_{t-2}$	0.655	3.920*** (.001)
$\Delta \ln EC_t$	0.491	1.014 (.321)
$\Delta \ln EC_{t-1}$	2.123	4.953*** (.000)
ΔPG_t	1.538	2.177** (.040)
Constant	0.347	0.407 (.687)
ECM(−1)	−0.368	−3.602*** (.001)
ecm = $\ln CO_2$ – 0.761 × $\ln Y$ – 0.063 × $\ln EC$ –4.185 × $\ln PG$ – 0.944 × Constant		
R^2: .678, DW-statistic: 2.109, Schwarz Bayesian Criterion (SBC): 6.148, F-stat.: 6.624*** (0.000)		
Model 3 (1970-2010)		
$\Delta \ln CO_{2t-1}$	−0.001	−0.008 (.992)
$\Delta \ln CO_{2t-2}$	0.314	2.249** (.033)
$\Delta \ln Y_t$	0.435	3.245*** (.003)
$\Delta \ln Y_{t-1}$	0.338	2.453** (.021)
$\Delta \ln Y_{t-2}$	0.704	4.458*** (.000)
$\Delta \ln EC_t$	1.044	3.197*** (.004)
$\Delta \ln EC_{t-1}$	1.792	5.319*** (.000)
ΔPG_t	1.310	1.909* (.067)
Constant	0.618	0.817 (.421)
ECM(−1)	−0.416	−4.110*** (.000)
ecm = $\ln CO_2$–0.621 × $\ln Y$–0.074 × $\ln EC$ – 3.146 × $\ln PG$ – 1.485 × Constant		
R^2: .702, DW-statistic: 2.236, Schwarz Bayesian Criterion (SBC): 8.385, F-stat.: 6.558*** (0.000)		

Note. ECM = error correction model.
***, **, and * are significant at 1%, 5% and 10% levels, respectively.

To further ensure the reliability of the estimates, diagnostic tests of serial correlation, functional form, normality, and heteroscedasticity were conducted and reported in Table 7. The results show that the null hypotheses for all the tests could not be rejected in Models 1 to 3, except for the functional form test in Models 1 and 2. This means that the three models are all free from serial correlation, heteroscedasticity, and normality problems. As such, these models could produce reliable results.

As suggested by Pesaran and Pesaran (1997), cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests for stability of the model along the studied periods were conducted. The results shown in Figures 1 to 6 illustrate that all three models were stable along the studied periods as the residuals were within the critical bounds at 5% significance level.

As a robustness check to the ARDL results, we have employed dynamic DOLS and FMOLS, and their estimated results are reported in Table 8. Both DOLS and FMOLS indicate that CO_2 emission has a significant positive relationship with GDP per capita, whereas population growth and energy consumption are insignificant in explaining CO_2 emission. The results further indicate that economic growth is the only significant determinant of CO_2 emission. This finding substantiates the long-run results of the ARDL, where economic growth is found to be the only significant determinant of CO_2 emission. The main focus of the study, which is population growth, has been revealed to impact insignificantly on CO_2 emission as earlier shown by long-run ARDL results.

Next, the causal relationship between the variables was examined by employing VECM Granger causality in a vector

Table 7. The Results of the Autoregressive Distributed Lag Diagnostic Tests.

Test statistics	LM version	*F*-version
Model 1		
A: Serial correlation	CHSQ (1) = 0.096 [.757]	*F*(1, 16) = 0.057 [.814]
B: Functional form	CHSQ (1) = 3.431* [.064]	*F*(1, 16) = 2.329 [.147]
C: Normality	CHSQ (2) = 0.950 [.622]	Not applicable
D: Heteroscedasticity	CHSQ (1) = 0.324 [.687]	*F*(1, 25) = 0.304 [.586]
Model 2		
A: Serial correlation	CHSQ (1) = 0.145 [.703]	*F*(1, 21) = 0.096 [.760]
B: Functional form	CHSQ (1) = 4.062 [.044]**	*F*(1, 21) = 3.053 [.095]*
C: Normality	CHSQ (2) = 0.617 [.734]	Not applicable
D: Heteroscedasticity	CHSQ (1) = 0.009 [.921]	*F*(1, 30) = 0.009 [.924]
Model 3		
A: Serial correlation	CHSQ (1) = 0.903 [.342]	*F*(1, 24) = 0.600 [.446]
B: Functional form	CHSQ (1) = 1.331 [.249]	*F*(1, 24) = 0.895 [.353]
C: Normality	CHSQ (2) = 0.409 [.815]	Not applicable
D: Heteroscedasticity	CHSQ (1) = 0.035 [.852]	*F*(1, 35) = 0.033 [.857]

Note. The values in brackets are probability values. LM = *lagrange multiplier;* A = Langrange multiplier test of residual serial correlation; B = Ramsey's RESET test using the square of the fitted values; C = Based on skewness and kurtosis of residual; D = Based on the regression of squared residuals on squared fitted values; CHSQ = chi-square.
***,, **, and * are significant at 1%, 5% and 10% levels, respectively.

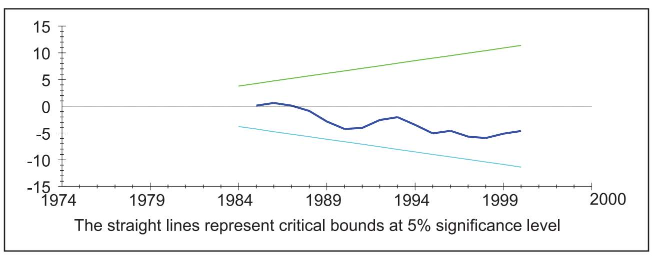

Figure 1. Plot of cumulative sum of recursive residuals for Model 1.

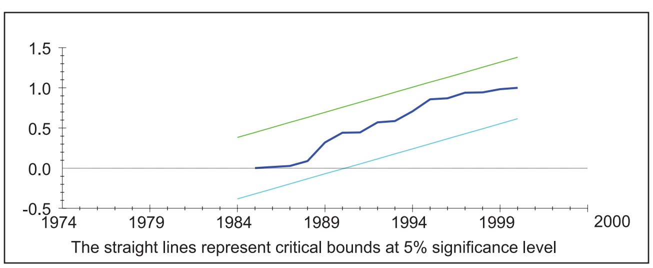

Figure 2. Plot of cumulative sum of squares of recursive residuals for Model 1.

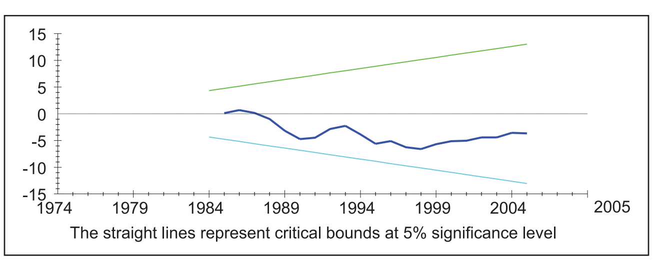

Figure 3. Plot of cumulative sum of recursive residuals for Model 2.

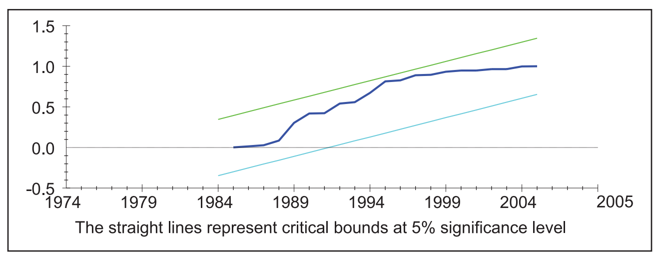

Figure 4. Plot of cumulative sum of squares of recursive residuals for Model 2.

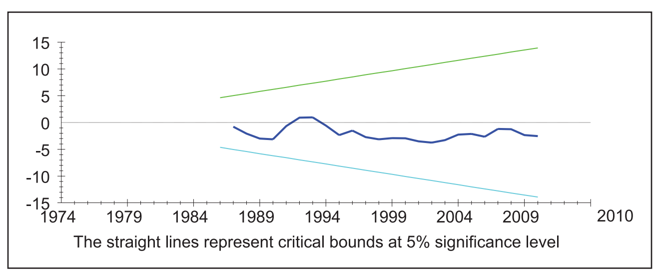

Figure 5. Plot of cumulative sum of recursive residuals for Model 3.

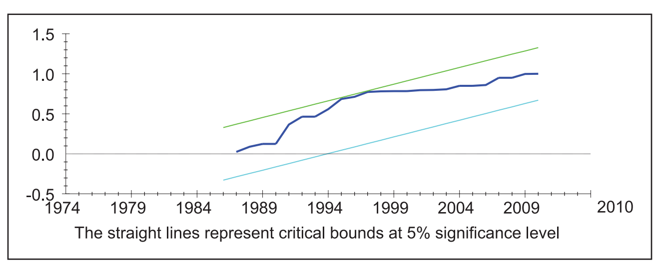

Figure 6. Plot of cumulative sum of squares of recursive residuals for Model 3.

Table 8. The Estimated Results for the Impact of Population Growth on CO_2 Emissions Using Panel DOLS and FMOLS.

Dependent variable = CO_2 emission: Regressors	Dynamic OLS		Fully modified OLS	
	Coefficient	*SE*	Coefficient	*SE*
Long-run coefficients				
GDP per capita	0.403** (2.488)	0.161	0.260** (2.255)	0.115
Population growth	0.085 (0.089)	0.954	0.101 (0.253)	0.401
Energy consumption	0.560 (1.701)	0.329	0.042 (0.223)	0.190
Constant	−4.824** (–2.152)	2.241	−2.483** (–2.424)	1.024

Note. Parentheses are the *t*-statistics. DOLS = dynamic ordinary least square; FMOLS = fully modified ordinary least square; OLS = ordinary least square.
**Indicates significant at 5% level.

Table 9. The Results of Vector Error Correction Model Granger Causality.

Dependent variables	Direction of causality				
	Short-run				Long-run
	$\sum \Delta \ln Y_t$	$\sum \Delta \ln PG_t$	$\sum \Delta \ln EC_t$	$\sum \Delta \ln CO_{2t}$	ECT_{t-1}
$\Delta \ln Y_t$	—	10.186** (.017)	8.038** (.045)	0.159 (.983)	−0.303**
$\Delta \ln PG_t$	13.064*** (.004)	—	4.968 (.174)	0.225 (.973)	−0.368
$\Delta \ln EC_t$	0.844 (.838)	3.421 (.331)	—	3.660 (.300)	−0.191
$\Delta \ln CO_{2t}$	0.221 (.974)	2.319 (.508)	9.788** (.020)	—	−0.483**
Diagnostic tests	Akaike information criterion= −11.396, VEC residual serial correlation LM test =15.321 (.501), VEC White heteroskedasticity test=270.644 (.312), VEC Jarque Bera normality test = 2.089 (.978)				

Note. Values in parentheses are the *p* values. LM = *lagrange multiplier;* VEC = vector error correction.
**Indicates significant at 5% level.

autoregression (VAR) system. The presence of cointegration as depicted by this study (refer to Table 4) suggests the existence of a casual relation in at least one direction. The estimated long- and short-run Granger causality results are presented in Table 9 and its summary in Table 10. The long-run Granger causality results reveal that ECT_{t-1} in economic growth equation is negative and statistically significant at 5% level. This suggests that there is a unidirectional causality running from population growth, energy consumption, and CO_2 emission to economic growth. This result substantiates the finding of Sulaiman (2014) in Nigerian context. It is also in line with the findings of Sulaiman and Abdul-Rahim (2017) and Ohlan (2015) for Malaysia and India, respectively. The result implies that reduction in fossil fuel energy consumption and CO_2 emission may harm economic growth in Nigeria, whereas increase in population will facilitate economic growth in the country, as increase in population will increase the size of the labor force required for productive activities.

Equally, the ECT_{t-1} in CO_2 emission equation is negative and statistically significant at 5% level, which indicates that CO_2 emission has bidirectional causality with economic growth and a unidirectional causality running from population growth and energy consumption to it. This result is also consistent with the finding of Sulaiman (2014) for Nigeria. The result indicates that CO_2 emission in Nigeria is driven by economic growth through massive fossil fuel energy consumption. Similarly, it infers that population growth causes CO_2 emission through increased

Table 10. The Summary of the Results of the Vector Error Correction Model Granger Causality Approach.

Direction of causality	Short-run (*F*-statistics)	Long-run (ECT_{t-1})
$\ln PG_t$ causes $\ln Y_t$	At 5% significance level	At 5% significance level
$\ln EC_t$ causes $\ln Y_t$	At 5% significance level	At 5% significance level
$\ln CO_{2t}$ causes $\ln Y_t$	No	At 5% significance level
$\ln Y_t$ causes $\ln PG_t$	At 5% significance level	No
$\ln EC_t$ causes $\ln PG_t$	No	No
$\ln CO_{2t}$ causes $\ln PG_t$	No	No
$\ln Y_t$ causes $\ln EC_t$	No	No
$\ln PG_t$ causes $\ln EC_t$	No	No
$\ln CO_{2t}$ causes $\ln EC_t$	No	No
$\ln Y_t$ causes $\ln CO_{2t}$	No	At 5% significance level
$\ln PG_t$ causes $\ln CO_{2t}$	No	At 5% significance level
$\ln EC_t$ causes $\ln CO_{2t}$	At 5% significance level	At 5% significance level

anthropogenic activities, which normally accompany growth in population. On the contrary, there is an evidence of absence of long-run causality in population growth and energy consumption equations, because the ECT_{t-1} in these equations is statistically insignificant. However, in the short run, a unidirectional causality runs from population growth and energy consumption to economic growth. Similarly, there is an evidence of short-run causality running from economic growth to population growth, and from energy consumption to CO_2 emission. The diagnostic tests' results of VECM reported in the lower part of Table 9 show that the model is stable and reliable as we could not reject all the null hypotheses, and therefore its estimates are acceptable for statistical inference.

Conclusions and Policy Recommendations

This study employed an ARDL approach to cointegration in a recursive form to ascertain the impact of population growth in the presence of economic growth and energy consumption on CO_2 emissions in Nigeria. The impact was tested based on three periods in recursive order: 1971-2000, 1971-2005 and 1971-2010. The study further employed VECM Granger causality to test the direction of causality between the variables in both short and long run. At first, this study tested for cointegration in all the models after selecting optimum lags and found that all the variables in the respective models were cointegrated. The long-run model was estimated and the results revealed that only economic growth was responsible for CO_2 emissions within the study period. Population growth and energy consumption were found to be insignificant in explaining CO_2 emissions. Besides the long-run model estimations, a short-run model was also estimated for all three cases. The results indicated that almost all the explanatory variables, that is, economic growth, population growth, and energy consumption were significant in influencing CO_2 emissions in the short run. This suggests that population growth, which is the focal point of this study, could only determine CO_2 emissions in the short run but not in the long run. Diagnostic tests were conducted for all the models, and the results revealed that they were all good fitted and have satisfied nearly all major classical linear regression requirements.

The robustness check was conducted using dynamic OLS and fully modified OLS, and their results confirmed the results of long-run ARDL model. The direction of causality was equally tested using VECM Granger causality, which revealed significant causality in only economic growth and CO_2 emissions models in the long run, whereas in the short run, causality was detected in economic growth, population growth, and CO_2 emissions models.

The main policy recommendation from this study is that population checking measures could be a short-run effective measure to reduce the CO_2 emissions. Therefore, a careful population stabilization policy in Nigeria can help to lower CO_2 emissions. However, population has insignificant impact on CO_2 emissions in the long run, but cautious population stabilization policy will equally assist in the long run. More so, encouraging the use of low carbon technologies like abatement equipment, renewal energy, and energy utilization efficiency can greatly assist in reducing CO_2 emissions without reducing energy consumption, and hence achieving sustainable economic growth. The study findings should pave the way for further research on how this identified problem can be solved.

Appendix A

Table A1. The Summary of the Variables' Names, Sources, Measurements, and Expected Signs.

Variables	Sources	Measurement	Expected sign
Economic growth	WDI	Real GDP per capita (constant 2005 US$)	+
Energy consumption	WDI	Fossil fuel energy consumption per capita (% of total)	+
CO_2 emission	WDI	CO_2 emissions (metric tons per capita)	Dependent variable
Population growth	WDI	Population growth rate (annual %)	+

Note. WDI = World Development Indicators of World Bank.

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