Symmetric and asymmetric effects of financial development on carbon dioxide emissions in Nigeria: Evidence from linear and nonlinear autoregressive distributed lag analyses

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Abstract
This study examines the impact of financial development on carbon dioxide emissions in Nigeria over the period 1971–2014. Income per capita, energy consumption, exchange rate and urbanization are incorporated in the analysis. The empirical analysis based on linear and nonlinear autoregressive distributed lag techniques provides evidence of long-run relationship among the variables in Nigeria. The results in general show that financial development has significant asymmetric effects on carbon dioxide emissions in Nigeria. Both short-run and long-run analyses show that the impact of positive changes in financial development on carbon dioxide emissions is significantly different from that of negative changes. The results suggest that in Nigeria positive shocks in financial development have significant reducing effect on carbon dioxide emissions, while negative shocks in financial development have significant increasing effect on carbon dioxide emissions. The empirical results also show that the response of carbon dioxide emissions to negative shocks in financial development is stronger. Based on these findings, this study concludes that mitigation policies would need to incorporate strategies to strengthen the depth of financial intermediation in the Nigerian economy.

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Keywords
Financial development, environmental pollution, nonlinear autoregressive distributed lag, asymmetry, Nigeria

Introduction
The Fifth Assessment Report of the United Nations’ Panel on Climate Change shows that the atmospheric concentration of carbon dioxide (CO₂) is higher than ever (see IPCC, 2014). Other international agencies have joined to warn of the severe and irreversible implications of the increasing concentration of greenhouse gases on the ecosystem and human welfare (see WHO, 2018; WWF, 2018). The burning of fossil fuels is considered the key driver. It is therefore not surprising that fossil fuel abundant economies are placed at the centre of this debate. This study considers the case of Nigeria. The Federal Republic of Nigeria has 36,972 million barrels of proven crude oil reserves (OPEC Annual Statistical Bulletin, 2019). Based on the average daily crude oil production of 1601.6 thousand barrels achieved in 2018 (OPEC Annual Statistical Bulletin, 2019), it would take over 60 years for Nigeria to run out of crude oil. The abundance of fossil fuel has however made Nigerian economy highly dependent on fossil fuels (Abam et al., 2014). The dependence of economic activities on fossil fuels has created enormous environmental concerns in the economy (Riti and Shu, 2016). The industrial, transportation, commercial sectors continue to depend on fossil fuels and the burning of fossil fuels continues to remain a major contributor to CO₂ emissions in the country, especially in the urban areas where private sector activities generate higher demand for energy (Elum and Momodu, 2017; Riti and Shu, 2016).

The abundance of fossil fuel in the Nigerian economy suggests the need for policy makers to identify economic conditions capable of diversifying energy consumption mix through research and development (R&D) of low-carbon energy sources. Here financial development takes a leading role. Theoretical literature suggests that financial development provides various economic conditions required to enhance private sector activities. Levine (1997), King and Levine (1993), Levine et al. (2000) and Levine (2005) identified these conditions to include mobilization and pooling of savings, provision of information and allocation of capital, diversification and management of risk, reduction in cost of borrowing, exertion of corporate governance, facilitation of transactions, and increase in transparency between creditors and borrowers. Financial development through these identified economic conditions increases access to credit, and access to credit promote trade and investment flows and enhance research and development (R&D) in technological activities in the economy (Hao et al., 2016; Danish et al., 2018; Shahbaz et al., 2018). These theoretical explanations have often been the incentive for the implementation of financial development and consolidation policies in developing economies.

This present study examines the impact of financial development on CO₂ emissions in Nigeria. In the literature, studies on the impact of financial development on CO₂ emissions in Nigeria are still very scanty. Thus far, the few available studies have reported mixed results due to either differences in estimation techniques, sample period covered or indicators of financial sector development used (see Cosmas et al., 2019; Rafindadi, 2016). In addition, these studies have assumed a linear relationship in the analysis, exploring only how financial development symmetrically impacts on CO₂ emissions in Nigeria. These
observations from existing studies imply that the debate on the impact of financial development on CO₂ emissions in Nigeria is still open. Part of the new revelation from recent studies drawing empirical evidence from other economies is that the relationship could be nonlinear with financial development having asymmetric impacts on CO₂ emissions (see Ahmad et al., 2018; Gök, 2020; Ibrahiem, 2020; Karasoy, 2019). The interest on the asymmetric effects of financial sector development on CO₂ emissions is based on the argument that the size and impact of a positive change can be different from the size and impact of a negative change in the absolute terms (Shahbaz et al., 2016).

In the light of the above discussion, this study undertakes robust empirical investigation of the impact of financial development on CO₂ emissions to appropriately inform sound environmental policies in Nigeria. The financial sector in Nigeria has evolved over the years, changing with developments and the needs of the economy. The various instituted strategic financial reforms and consolidation policies in the previous decades in response to challenges posed by globalization, technological innovation, changes in crude oil prices and other systematic and non-systematic factors have impacted on the depth of the Nigerian financial system (see Assaf et al., 2012; Barros and Caporale, 2012), highlighting the need to consider asymmetries in the relationship between financial sector development and CO₂ emissions. This study uses a longer sample period (1971–2014) than has been covered by other studies in the case of Nigeria and extends the analysis beyond linear relationship using a newly developed nonlinear autoregressive distributed lag (NARDL) technique (Shin et al., 2014) to uncover the size and impact of positive and negative changes (asymmetries) in financial development on CO₂ emissions in the economy. This study provides the first empirical understanding of how asymmetries in financial development impact on CO₂ emissions in Nigeria. Therefore, the results of this study provide policy makers a better understanding of how financial sector development impacts on the environmental component of sustainable development targets in Nigeria.

This study is structured as follows: literature review is provided in the following section. Data and method of the empirical study is provided in the ‘Empirical model, data and methodology’ section. The results from linear and nonlinear analysis are presented and discussed in the ‘Empirical results and discussion’ section. In the ‘Conclusion and policy implications’ section some concluding remarks on the findings are given, highlighting some policy implications.

**Literature review**

The role of financial development in stimulating economic activities through increased access to credit, promotion of investment flows and enhancement of R&D in technological activities has been the theoretical background for explaining the interaction between financial development and environmental quality indicators in recent studies (see Ahmad et al., 2018; Danish et al., 2018; Moghadam and Dehbashi, 2018; Saud et al., 2019). On one hand, there will be more emission of CO₂, if financial development and trade openness generate demands for energy using technologies and gadgets such as cars, and investment into energy intensive sectors such as transportation and oil and gas exploration sectors (Ehigiamusoe and Lean, 2019; Nasir et al., 2019; Xu et al., 2018). On the other hand, if financial development is incorporated into environment-friendly policies and regulations, credit facilities and investment channels provided by financial system and international trade may create enabling environment for R&D of low-carbon (clean) energy sources (Charfeddine and
Kahia, 2019; Moghadam and Dehbashi, 2018; Shahbaz et al., 2016). This is a required condition for giving households and other energy users in the economy access to low-carbon and efficient energy products (Chang, 2015; Islam et al., 2013; Keho, 2016). This means the proportion of fossil fuels in the energy consumption mix could decrease with policy options designed to strengthen the depth of financial intermediation. As such financial development could as well mitigate environmental degradation by reducing CO₂ emissions in the economy (Charfeddine and Kahia, 2019; Moghadam and Dehbashi, 2018).

Using the autoregressive distributed lag (ARDL) approach to cointegration, the vector error correction method (VECM) and the innovative accounting approach to Granger causality analysis, Shahbaz et al. (2013) examined the linkages among economic growth, energy consumption, financial development, trade openness and CO₂ emissions in Indonesia over the period 1975–2011. The results indicate that while energy consumption and economic growth generate CO₂ emissions in the oil-abundant economy, financial development and trade openness create economic conditions that reduce it. The VECM Granger causality analysis shows bidirectional causality between energy consumption and CO₂ emissions, economic growth and CO₂ emissions, and unidirectional causality running from financial development to CO₂ emissions. The impulse response analysis shows that the response of CO₂ emissions to shocks in financial development is negative.

Charfeddine and Khediri (2016) examined the relationship between financial development and CO₂ emissions based on the environmental Kuznets curve (EKC) hypothesis for the United Arab Emirates (UAE) over the period 1975–2011. The results show an inverted U-shaped relationship between financial development and CO₂ emissions in UAE indicating that initially CO₂ emissions increase as financial sector develops and then decline as financial sector matures to generate efficiency in resource allocation. Xu et al. (2018) used the autoregressive distributed lag (ARDL) model and VECM to examine the relationship between financial development and CO₂ emissions in Saudi Arabia over the period 1971–2016. The results show a significant positive relationship and bidirectional causality between financial development and CO₂ emissions in Saudi Arabia. Using the ARDL model, Moghadam and Dehbashi (2018) examined the impact of financial development on CO₂ emissions in Iran over the period 1970–2011. The results show that financial development increases CO₂ emissions in Iran. Salahuddin and Gow (2019) examined how technological innovation and financial sector development influence CO₂ emissions in Qatar using a number of econometric techniques covering the period from 1971 to 2014. The results suggest that financial development increases CO₂ emission in the economy. There also other studies that employed different
methods of analysis to uncover the impact of financial development on CO₂ emissions. An interesting one in this group is Gök (2020) which evaluated the impact of financial development on CO₂ emissions by meta-regression analysis using 275 estimation results from 72 existing empirical studies. The meta-regression analysis which identified various measures of financial development used in existing studies concludes that the impact of financial development on CO₂ emissions varies based on the econometric technique used by studies, countries or regions examined and time period covered by empirical analysis.

In the particular case of Nigeria, only few studies could be identified to have considered the impact of financial development on CO₂ emissions, with empirical analysis focusing on linear and symmetric relationship. Using the ARDL bounds technique, Rafindadi (2016) shows that financial development stimulates energy demand and lowers CO₂ emissions in Nigeria over the period 1971–2011. Interestingly, Cosmas et al. (2019) identified insignificant relationship between CO₂ emissions and financial development in Nigeria over the period from 1981 to 2016. These studies could therefore be extended by considering possible asymmetries in the relationship between CO₂ emissions and financial development in Nigeria.

**Empirical model, data and methodology**

**Empirical model, definition of variables and data description**

The role of financial development is considered a key factor in this study. Other variables considered in this study include energy consumption, exchange rate and urbanization. Annual data covering the period from 1971 to 2014 are used in this analysis. The following log-linear model specification is investigated

\[
\ln CO₂_t = \alpha_0 + \alpha_1 \ln EG_t + \alpha_2 \ln FD_t + \alpha_3 \ln EN_t + \alpha_4 \ln EXR_t + \alpha_5 \ln UB_t + \varepsilon_t
\] (1)

Where

- CO₂ represents CO₂ emissions in metric tons per capita, a measure of environmental pollution in Nigeria.
- EG represents gross domestic product (GDP) per capita (2010 constant US dollars), a measure of economic growth in Nigeria. According to the EKC hypothesis, environmental degradation is a by-product of growth in economic activities (Kaika and Zervas, 2013). Consequently, GDP per capita has been included in most recent modelling of environmental impacts (see Amri, 2018; Bento and Moutinho, 2016; Khan et al., 2019 among others). The EKC hypothesis predicts an inverted U-shaped relationship between economic growth and measures of environmental degradation, with economic growth increasing environmental pollution at the early stages of development and after a turning point level of income, generates improvement in environmental quality (Kaika and Zervas, 2013). In this study, the EKC hypothesis is examined following Narayan and Narayan (2010) approach, which involves comparing the long-run and short-run coefficients of GDP per capita. The EKC hypothesis exists if the long-run coefficient of GDP per capita is smaller than the short-run coefficient (Narayan and Narayan, 2010). This
method has recently been used by Bento and Moutinho (2016) and Amri (2018) to investigate the existence of EKC hypothesis for Italy and Tunisia, respectively.

- EN represents energy use (kg of oil equivalent per capita), a measure of energy consumption in Nigeria. UB represents urban population (% of total population), a measure of urbanization in Nigeria. Existing empirical studies have identified economic growth, energy consumption and urbanization among major determinants of CO₂ emissions (see Appiah, 2018; Liu and Bae, 2018; Pata, 2018; Rafindadi and Usman, 2019).
- EXR represents the official exchange rate (LCU per US$, period average). As the most important comprehensive price indicator for international transactions, exchange rate may exert significant impact on environmental quality via its influence on economic and technological activities (Zhang and Zhang, 2018). Therefore, this paper incorporates exchange rate in the model to explore its impact on carbon emissions in Nigeria. Data on these variables were obtained from the World Development Indicators, World Bank.
- FD represents financial development. Two indicators of financial sector development are used in this study: (1) Financial development index (FD-Index): a composite index constructed as a combination of three identified measure of financial development using principal component analysis (PCA). Table 1 presents the PCA estimates. The first component (PC1) explains 93% of the total standardized variations in the variables. FD – Index is constructed using the individual standardized variance of PC1 as the weights. (2) FD-PCB: the ratio of credit to the private sector by banks to GDP, a widely used indicator of financial development. The focus in the literature has been on how the financial sector stimulates economic activities through credit supply to the private sector, highlighting the importance of ensuring that this empirical analysis is robust against this key measure of financial development. Data on all the indicators of financial development are collected from the Global Financial Development Indicators, World Bank.

\( \varepsilon_t \) is the error term. All the variables are represented in natural logarithm form and this is indicated by \( \ln \). This is to eliminate the existence of any potential heteroscedasticity. The plots of the study variables are presented in Appendix 1 while the definitions and summary statistics are provided in Appendix 2.

### Table 1. Principal component analysis.

| Eigenvalues: \((\text{Sum} = 3, \text{Average} = 1)\) | Difference | Proportion | Cumulative Value | Cumulative Proportion |
|---|---|---|---|---|
| Number | Value | | | |
| 1. | 2.7900 | 2.6133 | 0.9300 | 2.7900 | 0.9300 |
| 2. | 0.1767 | 0.1434 | 0.0589 | 2.9667 | 0.9889 |
| 3. | 0.0333 | – | 0.0111 | 3.0000 | 1.0000 |

Eigenvectors (loadings):

| Variable | PC1 | PC2 | PC3 |
|---|---|---|---|
| Private credit by deposit money banks to GDP (%) | 0.5776 | −0.5724 | 0.5820 |
| Liquid liabilities to GDP (%) | 0.5637 | 0.7953 | 0.2228 |
| Deposit money banks’ assets to GDP (%) | 0.5904 | −0.1993 | −0.7821 |

Data sources: Global Financial Development Indicators, World Bank.
**Linear and nonlinear ARDL model**

The linear form of the ARDL-bound testing approach to cointegration analysis introduced by Pesaran et al. (2001) has been widely used in recent empirical analysis because of its statistical properties, considered superior to other long-run analytical techniques in the literature (see Abango et al., 2019; Aboagye, 2017; Nampewo and Opolot, 2016). This technique to cointegration is used to model the log-linear specification in equation (1) as follows

\[
D\ln CO_2_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}D\ln CO_2_{t-i} + \sum_{i=0}^{p} \alpha_{2i}D\ln EG_{t-i} + \sum_{i=0}^{p} \alpha_{3i}D\ln FD_{t-i} + \sum_{i=0}^{p} \alpha_{4i}D\ln EN_{t-i}
\]

\[
+ \sum_{i=0}^{p} \alpha_{5i}D\ln EXR_{t-i} + \sum_{i=0}^{p} \alpha_{6i}D\ln UB_{t-i} + \chi_T \chi_t + \varepsilon_t
\]

where \( \chi_T \) is a dummy variable that captures structural breaks in the data series. Pesaran et al. (2001) and Narayan (2005) provide upper and lower critical bounds for the evaluation of the null hypothesis of no cointegration among variables \( H_0 : \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11} = \alpha_{12} = 0 \). Comparing the computed F-statistic from equation (2) to the critical bounds, the null hypothesis is rejected when the calculated F-statistics is greater than the upper critical bound, accepted when it is less than the lower bound and considered inconclusive when the calculated F-statistics remains between the lower and upper critical bounds (see Narayan, 2005; Pesaran et al., 2001). Equation (3) presents the error correction model (ECM) explaining the short-run dynamics in the linear relationship in equation (2)

\[
D\ln CO_2_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}D\ln CO_2_{t-i} + \sum_{i=0}^{p} \alpha_{2i}D\ln EG_{t-i} + \sum_{i=0}^{p} \alpha_{3i}D\ln FD_{t-i} + \sum_{i=0}^{p} \alpha_{4i}D\ln EN_{t-i}
\]

\[
+ \sum_{i=0}^{p} \alpha_{5i}D\ln EXR_{t-i} + \sum_{i=0}^{p} \alpha_{6i}D\ln UB_{t-i} + \chi_T \chi_t + \lambda_1 ECM_{t-1} + \varepsilon_t
\]

where \( ECM_{t-1} \) is the error correction term. The role of the model is based on \( \lambda_1 \), which is the coefficient of \( ECM_{t-1} \). Econometrically, \( \lambda_1 \) is required to be negative and statistically significant to indicate that any short-run deviation will converge back to the long-run established equilibrium.

According to Shin et al. (2014), the NARDL model can be derived by extending the linear ARDL with the partial positive and negative sums decomposition of the exogenous variable, in this case \( \ln FD_t \) as follows

\[
\ln FD_t^+ = \sum_{j=1}^{t} \Delta FD_j^+ = \sum_{j=1}^{t} = \max(\Delta FD_j, 0)
\]
\[
\ln FD_{t}^- = \sum_{j=1}^{t} \Delta FD_{j}^- = \sum_{j=1}^{t} = \min(\Delta FD, 0)
\] (5)

Appendix 3 presents the plots of the positive and negative components of financial development indicators. Taking into account short-run and long-run asymmetric effects in the ARDL representation in equation (2) gives the NARDL models considered for estimation in this analysis as follows

\[
\begin{align*}
\Delta \ln CO_2_t &= \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta \ln CO_2_{t-i} + \sum_{i=0}^{p} \alpha_{2i} \Delta \ln EG_{t-i} + \sum_{i=0}^{p} \alpha_{3i}^+ \Delta \ln FD^+_{t-i} \\
&\quad + \sum_{i=0}^{p} \alpha_{3i}^- \Delta \ln FD^-_{t-i} + \sum_{i=0}^{p} \alpha_{4i} \Delta \ln EN_{t-i} + \sum_{i=0}^{p} \alpha_{5i} \Delta \ln EXR_{t-i} + \sum_{i=0}^{p} \alpha_{6i} \Delta \ln UB_{t-i} \\
&\quad + \alpha_7 \ln CO_2_{t-1} + \alpha_8 \ln EG_{t-1} + \alpha_9^+ \ln FD^+_{t-1} + \alpha_9^- \ln FD^-_{t-1} + \alpha_{10} \ln EN_{t-1} \\
&\quad + \alpha_{11} \ln EXR_{t-1} + \alpha_{12} \ln UB_{t-1} + \alpha_{Dum} TBrk_t + \epsilon_t
\end{align*}
\] (6)

From equation (6) the long-run coefficients defined as \(\alpha_9^+\) and \(\alpha_9^-\) will capture the long-run effects of positive and negative shocks in financial development on CO\(_2\) emissions, respectively. Also \(\sum_{i=0}^{p} \alpha_{3i}^+ \Delta \ln FD^+\) and \(\sum_{i=0}^{p} \alpha_{3i}^- \Delta \ln FD^-\) capture the short-run effects of the positive and negative shocks, respectively. The test for asymmetric relationship is implemented in two steps. First, cointegration (long-run relationship) among the variables is examined. As in the linear ARDL model, the computed F-statistic is compared to the upper and lower critical bounds from Narayan (2005) for the evaluation of \(H_0: \alpha_7 = \alpha_8 = \alpha_9^+ = \alpha_9^- = \alpha_{10} = \alpha_{11} = \alpha_{12} = 0\). The rejection of \(H_0\) is required to establish long-run relationship among the variables. Second, the long-run and short-run asymmetry in the relationship between financial development and CO\(_2\) emissions is tested using the Wald test. The presence of long-run asymmetry is confirmed by the rejection of the null hypothesis \(H_0: -\alpha_9^+/\alpha_7 = -\alpha_9^-/\alpha_7\). The Wald test is also employed in the implementation of the short-run symmetry test by evaluating the null hypothesis \(H_0: \sum_{i=0}^{p} \alpha_{3i}^+ \Delta \ln FD^+ = \sum_{i=0}^{p} \alpha_{3i}^- \Delta \ln FD^-\). The rejection of null hypothesis confirms the presence of short-run asymmetry in the relationship. Equation (7) presents the ECM explaining the short-run dynamics in the nonlinear relationship in equation (6)

\[
\begin{align*}
\Delta \ln CO_2_t &= \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta \ln CO_2_{t-i} + \sum_{i=0}^{p} \alpha_{2i} \Delta \ln EG_{t-i} + \sum_{i=0}^{p} \alpha_{3i}^+ \Delta \ln FD^+_{t-i} \\
&\quad + \sum_{i=0}^{p} \alpha_{3i}^- \Delta \ln FD^-_{t-i} + \sum_{i=0}^{p} \alpha_{4i} \Delta \ln EN_{t-i} + \sum_{i=0}^{p} \alpha_{5i} \Delta \ln EXR_{t-i} + \sum_{i=0}^{p} \alpha_{6i} \Delta \ln UB_{t-i} \\
&\quad + \alpha_{Dum} TBrk_t + \lambda_2 \ln ECM_{t-1} + \epsilon_t
\end{align*}
\] (7)

where a negative and statistically significant \(\lambda_2\), the coefficient of \(ECM_{t-1}\), predicts that any short-run deviation will converge back to the long-run established equilibrium. Furthermore, the adjustment asymmetry is investigated to extract the asymmetric
cumulative dynamic multiplier on \( \ln CO_2_t \) for unit changes in \( \ln FD_t^+ \) and \( \ln FD_t^- \) by implementing

\[
Z_{\theta}^+ = \sum_{j=0}^{h} \phi \ln CO_2_{t+j}, \quad Z_{\theta}^- = \sum_{j=0}^{h} \phi \ln FD_t^-
\]

It is expected that as \( \theta \to \infty \), then \( Z_{\theta}^+ \) and \( Z_{\theta}^- \) to the asymmetric long-run coefficients \( \alpha_9^+/\alpha_7 \) and \( \alpha_9^-/\alpha_7 \), respectively.

**Empirical results and discussion**

**Unit root tests**

Three unit root tests are performed to identify the stationarity properties of the series. The first two tests, augmented Dickey–Fuller and Phillips–Perron tests, investigate the stationarity properties of the series without accounting for structural changes in the series. Thus, the third test, Lee and Strazicich (2003), is also considered. Results from the augmented Dickey–Fuller and Phillips–Perron tests indicate that all the variables are only stationary at first difference (see Table 2). The results of Lee and Strazicich (2003) Lagrange multiplier unit root test that considers possible multiple structural breaks in the series are presented in Table 3. The results suggest that \( \ln FD – Index^- \), \( \ln FD – PCB^+ \) and \( \ln UB \) are stationary at level while other variables are stationary at first difference. Interestingly, structural breaks are identified in all the series. For example, the test suggests structural breaks in the CO\(_2\) emissions (\( \ln CO_2 \)) series in 1987 and 2000. This means that Nigeria observed significant policy shocks in CO\(_2\) emissions following the Structural Adjustment Program (SAP) in 1986 and the various economic policies that started the transition from military rule to democratic government in 1999. The summary of the unit root analysis is that none of the

| Table 2. Unit root tests without structural break. |
|-------------------------------------------------|
| Augmented Dickey–Fuller test | Phillips–Perron test |
|--------------------------------|---------------------|
| \section*{Level form I(0)} \section*{First difference I(1)} | \section*{Level form I(0)} \section*{First difference I(1)} \section*{Result} |
| \( \ln CO_2 \) | -1.3445 | -5.4438*** | -1.1697 | -8.7569*** | I(1) |
| \( \ln EG \) | -1.2438 | -4.5252*** | -0.5698 | -4.3256*** | I(1) |
| \( \ln FD-Index \) | -2.1389 | -4.5676*** | -2.0024 | -4.5904*** | I(1) |
| \( \ln FD-Index^+ \) | -1.2882 | -4.7479*** | -1.8332 | -4.6677*** | I(1) |
| \( \ln FD-Index^- \) | -0.6549 | -5.4535*** | -0.7052 | -5.4817*** | I(1) |
| \( \ln FD-PCB \) | -2.2853 | -4.7241*** | -1.9788 | -4.6163*** | I(1) |
| \( \ln FD-PCB^+ \) | -1.3735 | -4.6014*** | -1.0450 | -4.1863*** | I(1) |
| \( \ln FD-PCB^- \) | -0.5538 | -5.2575*** | -0.6126 | -5.2676*** | I(1) |
| \( \ln EN \) | -2.0585 | -5.5070*** | -2.3200 | -5.4368*** | I(1) |
| \( \ln EXR \) | -0.3698 | -5.2911*** | -0.4497 | -5.2824*** | I(1) |
| \( \ln UB \) | -0.8544 | -3.7663*** | -0.1950 | -3.7663*** | I(1) |

FD-Index: financial development index.
Note: *** indicate significance at 1% level.
The ARDL bounds test is known to be sensitive to lag selection. As the required initial step, the lag selection test was implemented with the Akaike information criterion suggesting lag 3 as the most suitable lag for the ARDL bounds analysis. TBrk captures significant policy shocks in CO₂ emissions following the SAP in 1986 and the various economic policies that started the transition from military rule to democratic government in 1999. Table 4 presents the F-statistics for the two specifications of the linear ARDL model. In the two specifications presented in Table 5, financial sector development is decomposed into positive and negative partial sums to examine nonlinearity in the relationship between financial development and CO₂ emissions. The results of all the linear and nonlinear specifications reject the null hypothesis of no cointegration, showing that long-run causal relationship exists.
among the variables in Nigeria. The cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) were applied to ascertain the stability of the parameters of the investigated linear and nonlinear models. These stability tests yield the graphs in Appendix 4, showing that the estimates from the linear and nonlinear models are stable and can support policy analysis and formulation.

### Linear ARDL Analysis

The short-run and long-run estimates from the linear ARDL model are presented in Table 6. In Part A, the short-run coefficients of economic growth (ΔlnEG), financial development indicators (ΔlnFD-Index and ΔlnFD-PCB) and energy consumption (ΔlnEN) are positive and statistically significant at 1% level. These results suggest that economic growth, financial development and energy consumption contribute significantly to environmental degradation in the form of CO₂ emissions in Nigeria in the short-run. The coefficient of urbanization (ΔlnUB) is negative and statistically significant at 1% level, suggesting that in Nigeria, urbanization does not contribute to CO₂ emissions in the short-run. The coefficient of lagged error correction term ECM(−1) is negative and statistically significant at 1% level in the two specifications. The negative value is theoretically expected and suggests the restoration of the long term equilibrium after an exogenous shock.

The long-run estimates from the linear ARDL model presented in Part B of Table 7 show a positive and statistically significant coefficient for economic growth, financial development, energy consumption and exchange rate. From the coefficient of lnFD-Index, a 1% increase in financial development increases CO₂ emissions in Nigeria by 0.051%. The long-run impact of financial development on CO₂ emissions is higher when credit to the private sector by banks is used as a measure of financial development in Nigeria. From the coefficient of lnFD-PCB, a 1% increase in credit to the private sector by banks increases CO₂ emissions in Nigeria by 0.752%. The coefficients show that energy consumption (lnEN) generates CO₂ emissions in Nigeria more than any other variable in the model. Following Narayan and Narayan (2010) approach for investigating the EKC hypothesis, the long-run and short-run coefficients of economic growth variable (lnEG) are compared. The estimates show that the long-run coefficient is smaller than the short-run coefficient. This condition according to Narayan and Narayan (2010) suggests that the EKC hypothesis exists in the

| Specifications | TBrk | F-statistic |
|----------------|------|-------------|
| 1 F₇CO₂{lnCO₂|lnEG, lnFD-Index⁺, lnFD-Index⁻, lnEN, lnEXR, lnUB, TBrk} | 1987, 2000 | 12.6742*** |
| 2 F₇CO₂{lnCO₂|lnEG, lnFD-PCB⁺, lnFD-PCB⁻, lnEN, lnEXR, lnUB, TBrk} | 1987, 2000 | 7.3737*** |

Critical value bounds

| Type | 1% | 5% | 10% |
|------|----|----|-----|
| I0 Bound | 3.505 | 2.618 | 2.218 |
| I1 Bound | 5.121 | 3.863 | 3.314 |

FD-Index: financial development index.

Source of asymptotic critical value bounds: Narayan (2005) using restricted intercept and no trend.

*** indicates rejection of the null hypothesis of no cointegration at 1% level of significance.
Overall, the linear analysis suggests the increasing impact of financial development on CO₂ emissions in Nigeria.

Nonlinear ARDL analysis

The short-run and long-run estimates from the nonlinear ARDL analysis are presented in Table 7. The short-run estimates in Part A and the long-run estimates in Part B confirm that economic growth (\(\ln\)EG) and energy consumption (\(\ln\)EN) increase CO₂ emissions in Nigeria. Confirming the estimates from the linear model, the results in Table 7 show that energy consumption (\(\ln\)EN) contributes to CO₂ emissions in Nigeria more than other variables in the model. Using Narayan and Narayan (2010) approach for investigating the EKC hypothesis, the long-run and short-run coefficients of economic growth variable (\(\ln\)EG) are compared. The estimates confirm the results from the linear ARDL model with the long-run coefficient smaller than the short-run coefficient. The results support the condition for the existence of EKC hypothesis in the case of Nigeria. The lagged error correction term ECM(−1) has a negative coefficient statistically significant at 1% level, confirming the existence of long-run relationship among the variables.

Table 6. Linear relationship between financial development and CO₂ emissions.

| Variable     | Specification 1 (FD = FD-Index) | Specification 2 (FD = FD-PCB) |
|--------------|----------------------------------|--------------------------------|
|              | Coefficient | t-Statistic | P-value   | Coefficient | t-Statistic | P-value   |
| Part A: Short-run estimates |             |             |           |             |             |
| \(\Delta \ln\)CO₂(−1) | 0.0621 | 0.6372 | 0.5295 | 0.0522 | 0.5243 | 0.6045 |
| \(\Delta \ln\)CO₂(−2) | 0.2231** | 2.4163 | 0.0230 | 0.2889*** | 2.9146 | 0.0072 |
| \(\Delta \ln\)EG | 2.1377*** | 6.5680 | 0.0000 | 2.4211*** | 6.6998 | 0.0000 |
| \(\Delta \ln\)EN | −0.8458** | −2.1345 | 0.0424 | −0.9743** | −2.5349 | 0.0176 |
| \(\Delta \ln\)FD-Index | 0.0533*** | 6.3997 | 0.0000 |              |      |           |
| \(\Delta \ln\)FD-Index(−1) | −0.0299*** | −3.4878 | 0.0017 |              |      |           |
| \(\Delta \ln\)FD-PCB |              |      |           | 0.6961*** | 6.0783 | 0.0000 |
| \(\Delta \ln\)FD-PCB(−1) |              |      |           | −0.5742*** | −4.9370 | 0.0000 |
| \(\Delta \ln\)EN | 3.6168*** | 4.2901 | 0.0002 | 2.4963*** | 2.8101 | 0.0093 |
| \(\Delta \ln\)EXR | 0.0250 | 0.4319 | 0.6694 | 0.0082 | 0.1371 | 0.8920 |
| \(\Delta \ln\)UB | −2.8726** | −3.3475 | 0.0025 | −3.0564*** | −3.4293 | 0.0020 |
| \(\Delta \ln\)TBrk | 0.2759*** | 4.4698 | 0.0001 | 0.2386*** | 3.9030 | 0.0006 |
| ECM(−1) | −0.5331*** | −5.4486 | 0.0000 | 0.6555*** | −6.3588 | 0.0000 |
| Part B: Long-run estimates |             |             |           |             |             |
| C | −23.4145*** | −2.8295 | 0.0089 | −21.6005** | −2.7251 | 0.0113 |
| \(\ln\)EG | 0.4383** | 2.1862 | 0.0380 | 0.4424** | 2.3254 | 0.0281 |
| \(\ln\)FD-Index | 0.0508*** | 4.6033 | 0.0001 |              |      |           |
| \(\ln\)FD-PCB |              |      |           | 0.7521*** | 5.0902 | 0.0000 |
| \(\ln\)EN | 5.3361*** | 3.6987 | 0.0010 | 5.0219*** | 3.5954 | 0.0013 |
| \(\ln\)EXR | 0.3686*** | 2.9624 | 0.0064 | 0.3642*** | 3.1431 | 0.0041 |
| \(\ln\)UB | −4.9462*** | −4.6043 | 0.0001 | −5.1544*** | −4.8328 | 0.0001 |

ECM: error correction model; FD-Index: financial development index.
Note: ** and *** indicate significance at 5% level and 1% level, respectively.
The sign and size of the coefficient of $\ln FD - \text{Index}^+$ and $\ln FD - \text{Index}^-$ in Table 7 show how positive and negative changes in financial development, respectively, would impact on CO2 emissions in Nigeria. Considering the sign of the coefficients, the short-run and long-run estimates show that positive innovations in financial development have negative coefficients that are significant at 5% level while negative innovations in financial development have positive coefficients, significant at 1% level. In specification 1, the sizes of the long-run coefficients of $\ln FD - \text{Index}^+$ and $\ln FD - \text{Index}^-$ are 0.30 and 0.60, respectively. The respective long-run coefficients in specification 2 for $\ln FD - \text{PCB}^+$ and $\ln FD - \text{PCB}^-$ are 0.20 and 0.61. These estimates show that a 1% increase in financial development when measured as bank credit to the private sector decreases CO2 emissions in Nigeria by 0.20% in the long-run. Similarly, a 1% decrease in bank credit to the private sector increases CO2 emissions by 0.61% in the long-run. Comparatively, the impact of negative shocks in

| Variable | Specification 1 (FD = FD-Index) | Specification 2 (FD = FD-PCB) |
|----------|---------------------------------|--------------------------------|
|          | Coefficient | t-Statistic | Prob. | Coefficient | t-Statistic | Prob. |
| Part A: Short-run estimates | | | | |
| $\Delta \ln CO2(-1)$ | 0.1918*** | 2.5099 | 0.0189 | 0.4276*** | 3.6879 | 0.0012 |
| $\Delta \ln CO2(-2)$ | 0.2383*** | 3.6788 | 0.0011 | 0.4618*** | 5.0738 | 0.0000 |
| $\Delta \ln EG$ | 1.8349*** | 8.7892 | 0.0000 | 2.4454*** | 8.5956 | 0.0000 |
| $\Delta \ln FD - \text{Index}^+$ | -0.0217*** | -2.3388 | 0.0276 | | | |
| $\Delta \ln FD - \text{Index}^-$ | -0.2402*** | 11.5995 | 0.0000 | | | |
| $\Delta \ln FD - \text{Index}^+(-1)$ | -0.0254*** | -3.1707 | 0.0040 | | | |
| $\Delta \ln FD - \text{PCB}^+$ | -0.3421*** | -2.6557 | 0.0141 | | | |
| $\Delta \ln FD - \text{PCB}^-$ | 1.3737*** | 9.6692 | 0.0000 | | | |
| $\Delta \ln EN(-1)$ | 4.0138*** | 7.0644 | 0.0000 | 4.0849*** | 5.7386 | 0.0000 |
| $\Delta \ln EN$ | -0.1353 | -1.6119 | 0.1206 | | | |
| $\Delta \ln EXR$ | 0.0175 | 0.4524 | 0.6549 | -0.0135 | -0.3472 | 0.4652 |
| $\Delta \ln UB$ | 14.3069*** | 10.0613 | 0.0000 | 27.7074*** | 9.2125 | 0.0000 |
| $\Delta TBrk$ | 0.2765*** | 6.6545 | 0.0000 | 0.2359*** | 4.8582 | 0.0001 |
| ECM(-1) | -1.0794*** | -10.8634 | 0.0000 | -1.5765*** | -9.2853 | 0.0000 |
| Part B: Long-run estimates | | | | |
| $\Delta \ln EN(-1)$ | -27.0429*** | -7.4442 | 0.0000 | -29.9237*** | -7.5928 | 0.0000 |
| $\Delta \ln EG$ | 0.4358*** | 5.4972 | 0.0000 | 0.6677*** | 9.5174 | 0.0000 |
| $\Delta \ln FD - \text{Index}^+$ | -0.2992** | -2.2684 | 0.0322 | | | |
| $\Delta \ln FD - \text{Index}^-$ | 0.6004*** | 4.9868 | 0.0000 | | | |
| $\Delta \ln FD - \text{PCB}^+$ | -0.1992*** | -2.2972 | 0.0310 | | | |
| $\Delta \ln FD - \text{PCB}^-$ | 0.6134*** | 4.7527 | 0.0001 | | | |
| $\Delta \ln EN$ | 3.4519*** | 5.4378 | 0.0000 | 3.8552*** | 5.6722 | 0.0000 |
| $\Delta \ln EXR$ | 0.1678*** | 3.8728 | 0.0007 | 0.1338*** | 3.8947 | 0.0007 |
| $\Delta \ln UB$ | 0.4231 | 0.6384 | 0.5290 | -0.0596 | -0.9562 | 0.9247 |
| Part C: Wald test for asymmetry | | | | |
| Short-run | 1.0227 | 0.0078 | 10.1038 | 0.0043 |
| Long-run | 3.8648 | 0.0493 | 4.6753 | 0.0393 |

ECM: error correction model; FD-Index: financial development index.
Note: ** and *** indicate significance at 5% level and 1% level, respectively.
financial development on CO$_2$ emissions in Nigeria is identified to be stronger than the reducing effect of a unit positive shock in financial development.

The results in Part C of Table 7 confirm the presence of long-run asymmetry by rejecting the null hypothesis at 5% significant level in the two specifications implemented. The Wald test also confirms the presence of short-run asymmetry in the relationship at 1% level of significance. Interestingly, the dynamic multiplier graph in Figure 1 confirms that the impact of negative shocks in financial development exceeds the impact of positive shocks in the variable in the case of Nigeria.

**Conclusion and policy implications**

This study examines the effects of financial development on CO$_2$ emissions in Nigeria over the period 1971–2014. Income per capita, energy consumption, exchange rate and urbanization are incorporated in the analysis. The empirical analysis explores two environmental models: the first model based on linear ARDL technique and the second model based on nonlinear ARDL framework. The linear ARDL model considered as a benchmark analysis explores the symmetric effects of financial development on CO$_2$ emissions in Nigeria. The nonlinear ARDL model decomposed financial development into positive and negative partial sum to explore possible asymmetric effects of financial development on CO$_2$ emissions in Nigeria. The idea for testing the asymmetric effects of financial development is to determine how negative (a decline in the depth of financial development) and positive (an increase in the depth of financial development) impact on CO$_2$ emissions in the economy. The ARDL bounds cointegration analysis provides evidence of the presence of long-run relationship between CO$_2$ emissions, financial development, economic growth, energy consumption, exchange rate and urbanization in Nigeria.

The results of the linear ARDL show that financial development has positive effects on CO$_2$ emissions. Interestingly, the results from the estimated nonlinear ARDL model indicate that the impact of positive shocks in financial development on CO$_2$ emissions in Nigeria is significantly different from that of negative shocks: positive changes reduce CO$_2$ emissions while negative changes increase CO$_2$ emissions. Based on these findings, this study concludes that existing studies have imposed a too restrictive assumption on the interaction between
financial development and CO₂ emissions in Nigeria by focusing on the linear relationship among the variables. This study shows that economic growth and exchange rate depreciation contribute to CO₂ emissions in Nigeria. Importantly, the results also highlight the consequences of energy use on the environment. The implication being that ensuring sustainability in the Nigerian economy would require policies that could spur economic growth at a least cost to the environment by encouraging research, development and substitution towards low-carbon energy sources. Based on these findings, this study concludes that mitigation policies would need to incorporate strategies to strengthen the depth of financial intermediation in the Nigerian economy.

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**Appendix 1. Time series plot of the study variables (1971–2014)**

- **CO₂ emissions (metric tons per capita)**
- **GDP per capita (constant 2010 US$)**
- **Energy use (kg of oil equivalent per capita)**
- **Private credit by deposit money banks to GDP (%)**
- **Financial Development Index**
- **Urban population (% of total population)**
- **Official exchange rate (LCU per US$, period average)**
Appendix 2. Definition of variables and descriptive statistics

| Variables | Definition | Mean   | Maximum | Minimum | Std. dev. |
|-----------|------------|--------|---------|---------|-----------|
| CO₂       | CO₂ emissions (metric tons per capita) | 0.6478 | 1.0100  | 0.3256  | 0.1898    |
| EG        | GDP per capita (constant 2010 US$)    | 1754.0300 | 2563.9000 | 1324.2970 | 371.4107  |
| EN        | Energy use (kg of oil equivalent per capita) | 694.8266 | 798.6302 | 579.0784 | 53.6055   |
| FD-PCB    | Private credit by deposit money banks to GDP (%) | 9.8865 | 20.1609 | 4.1780 | 4.3357    |
| FD-Index  | Financial development index           | 13.8846 | 26.8316 | 6.1557 | 5.9323    |
| UB        | Urban population (% of total population) | 30.9985 | 46.9820 | 18.1510 | 8.6435    |
| EXR       | Official exchange rate (LCU per US$, period average) | 52.5727 | 158.5526 | 0.5468 | 62.6485   |

Data on CO₂, EG EN, UB and EXR are from the World Development Indicators, World Bank; data on FD-PCB are from the Global Financial Development Indicators, World Bank; FD-Index is constructed using PCA (see Table 1).

Appendix 3. Positive (POS) and negative (NEG) components of financial development indicators (1971–2014)
Appendix 4. CUSUM and CUSUMSQ plots

Plots for Linear Model Specification 1

Plots for Linear Model Specification 2

Plots for Nonlinear Model Specification 1

Plots for Nonlinear Model Specification 2