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Environmental degradation and economic growth: time-varying and nonlinear evidence from Nigeria

Andisheh Saliminezhad[1] · **Huseyin Ozdeser**[1] · **Dahiru Alhaji Bala Birnintsaba**[1]

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Abstract
The current study investigates the causal relations between CO2 emissions and the growth of Nigeria's economy, a topic of significant interest for the relevant authorities that has yet to be comprehensively examined. We test both the nonlinear and time-varying nature of the variables' relationships to provide effective and applicable policies. Unlike the linear method's lack of causal evidence, both nonlinear and time-varying Granger causality tests indicate the presence of dual causation between the variables. This suggests that appropriate and cost-effective environmental policies need to be adopted in Nigeria to prevent sustainable economic growth from being jeopardized while addressing environmental concerns. In this regard, it is recommended that clean energy resources make a greater contribution to the country's energy paradigm as a viable solution. This will lead to higher energy efficiency, which will help the country to maintain the economy's growth level in the ideal zone and mitigate environmental challenges.

Keywords Economic growth · CO2 emissions · Nonlinear granger · Time-varying analysis · Nigeria

JEL Classifications O11 · Q54 · C54

1 Introduction

As an adverse environmental phenomenon, climate change is considered a certain irregularity in the climate systems, which has become a tremendous concern worldwide. These anomalies are caused by the increase in the concentration of harmful CFCs (chlorofluorocarbons), HFCs (Hydrofluorocarbons), and GHGs (greenhouse gases) in the global atmosphere, which are the primary factors causing the warming of the Earth.

✉ Andisheh Saliminezhad
Andisheh.saliminezhad@neu.edu.tr

Huseyin Ozdeser
huseyin.ozdeser@neu.edu.tr

Dahiru Alhaji Bala Birnintsaba
dahirubala5002@gmail.com

[1] Department of Economics, Near East University, Nicosia/TRNC, Cyprus

Interest on global warming has recently gained momentum in most communities, but evidence shows that this phenomenon is already starting to have an impact, as indicated by the global temperature rise from 0.4 to 0.8 °C during the past 100 years. Beyioku (2016) observed that climate change predominantly results from the expansion of the activities of humans around the world. This affects well-being while also causing long-term negative impacts resulting in continued threats around the world due to the increasing problems connected to changes in the global climate.

The causes and consequences of global warming have been widely discussed among scholars from various perspectives. Some of the reasons that have been particularly highlighted as causes of the rise in environmental degradation include: the rise in ecological footprint; human activities such as considerable migration from rural areas to urban areas with the hope of finding a better life quality, bush burning and deforestation; poor water resource management; soil erosion; food shortages and the combustion of carbon-based materials (Abbas et al., 2016, 2018a, 2018b, 2020a, 2021). Several studies have also indicated the detrimental effects of changes in the climate, including increased temperatures, desertification, and drought (Abbas et al., 2020b). However, one of the most relevant consequences of global warming threatening low-lying coastal countries such as Nigeria is the coastal erosion resulting from the rising sea levels. It is evident that the rising temperatures are leading to a rise in sea level, increasing the chance of flooding and property damage (see Sulaiman & Abdul-Rahim, 2018).

Regarding the adverse impacts of climate change, scholars have further demonstrated that although climate change will be experienced worldwide, developing nations will feel the impacts more intensely, particularly African countries, due to their poor ability to adapt (Nwafor, 2007 and Jagtap, 2007). Wade and Jennings (2015), as well as McMichael et al. (2015), classified African and Asian countries as having a higher vulnerability to changes in the climate; for instance, Nigeria, which is characterized by its dense population, is recognized as being particularly exposed to the consequences of changes in the climate. Nigeria experiences very high temperatures, ranging between 12 and 38 °C, due to seasonal precipitation patterns, which range between 50 and 430 cm. This concurs with Ruth (2017), who recognized Nigeria as being affected by climate change through different climate change-related causes.

Due to the consensus that greenhouse gas emissions are warming the world's climate, studies have progressively centered on evaluating the effects that are likely to occur. Any climate change investigations must incorporate a model that interprets changes in climate-related factors and their relation with economic indicators. Evaluating the shocks of climatic changes in the global economy is a task that possesses a multifaceted nature. The arrangement of systems through which climate may impact the economy, directly or indirectly, is, to a great degree, substantial and challenging for an exhaustive examination.

Regardless of whether the impacts of climate change on each applicable component have been determined, it is essential to investigate how different factors combine to impact the macroeconomic results. Among the available macroeconomic indicators, economic growth is an essential element whose relationship environmental quality has gained considerable attention among scholars. The main concern observed in the vast body of the literature assessing this popular nexus relates to identifying their causal relation under the defined framework of the so-called environmental Kuznets curve (EKC) proposed by Kuznets (1955). His hypothesis asserts that the potential association between CO2 emissions and economic growth follow a nonlinear pattern in the form of an inverted U-shaped pattern (Stern, 2004).

Numerous researchers are now choosing to focus their efforts on climate change research, which signifies the need to examine how environmental factors impact the growth of economies (Purcel, 2020). This issue is of great interest, particularly in countries like Nigeria. Following the country's economic diversification through the expansion of the industrial and manufacturing sectors that started in the 1960s; Nigeria became heavily dependent on fossil fuels for its energy needs leading to a higher level of CO2 emissions. This has subsequently triggered a controversial debate on the trade-off between seeking a higher level of growth and addressing the problem of global warming among the country's relevant authorities. Moreover, researchers have demonstrated that Nigeria is now suffering from various issues in nature, which have been unequivocally linked to the ongoing problem of changes in the climate (Akpodiogaga & Odjugo, 2010; Ayuba et al., 2007). All of these issues motivate us to investigate how CO2 emissions and economic growth can affect each other.

Multiple researchers have attempted to assess the linkage between the two indicators of CO2 emissions and economic growth in different samples. They have employed distinct methodologies for various time spans in several samples. Nevertheless, only a limited number of scholars have studied the influence of CO2 emissions on the growth of the economy within Nigeria. Bouznit et al. (2016) analyzed the association between CO2 emissions and the growth of the Algerian economy as the third largest emitter of CO2 on the African continent. Adopting the Autoregressive Distributed Lag methodology, they indicated that Algeria's economic growth would result in more emissions. Sulaiman et al. (2014) detected a relationship among the consumption of energy, carbon dioxide (CO2) emissions, and growth of the economy in Nigeria using the Toda and Yamamoto procedures. The result indicated a causal direction only existed running from CO2 emissions to the growth of the economy. The authors suggested that renewable energy could be considered an alternative energy source to lower CO2 emissions while sustaining economic growth in the long horizon. Akpan and Akpan (2012) employed a Multivariate Vector Error Correction (VECM) framework to examine the long-run and causal relationship between electricity usage, carbon emissions, and economic growth in Nigeria between 1970 and 2008. The findings showed that economic growth is linked with a long-run rise in carbon emissions, implying that the growth process in Nigeria causes high levels of pollution. Furthermore, the output of the Granger causality test indicated a one-way causal flow from the growth of the economy to carbon emissions. Muftau (2014) empirically investigated the association between the same series using the Fixed Effects Panel Regression Model for West African nations over the period 1970–2011. The study showed that the degree of environmental pollution reflects the rates of economic growth in these countries. The non-causality results showed that economic growth contributes to carbon dioxide emissions, which was supported through the estimated significant positive nexus between the variables. Akanbi et al. (2014) examined the inter-relationships between human development, climate change, and economic growth in the context of Nigeria. Applying quantitative analysis, they found that climate was an obstacle to human development, causing an adverse impact in Nigeria. The authors offered perpetual engagement of the government to perform policies that minimize human capital development barriers and increase economic growth in Nigeria. Abidoye and Odusola (2015) investigated the association between economic growth as one indicator and change in climate as another indicator in Africa, adopting cross-sectional data related to 34 nations covering the period 1961–2009. They discovered that changes in the climate had a detrimental influence on African nations' growth. Zhao et al. (2017) evaluated the effects that economic growth had on the emissions of

CO2 and revealed that intensive consumption of energy by the industrial sector has the potential to decouple economic growth in China. In related research, Mardani et al. (2018) conducted a general examination of the relation between the emissions of CO2 and output growth by applying PRISMA analysis that covered studies of 175 articles by 55 authors published between 1995 and 2017. Their findings showed that, due to the bidirectional causality between CO2 and the growth of the economy, policymakers attempted to reduce emissions by changing economic growth strategies.

Empirical studies examining the CO2–growth linkages mainly present their relations in a linear framework by imposing some prior assumptions. However, it is possible to state that these assumptions cannot be well-grounded and validated in the real world. It is not wrong to say that the inconclusive results provided in the literature can potentially be attributed to the applied methodologies. This draws attention to the need for official authorities to make decisions and develop policies based on robust inferences. Hence, assessing the link between the variables with a more reliable and comprehensive framework will be of great interest and importance to provide a more proper background for the relevant authorities with a higher degree of trust. It is evident that their linkages can face many nonlinearities and structural breaks, which emerge from various political changes and different sets of regulations. When nonlinearities exist, almost all standard frameworks such as linear Granger causality are prone to misspecification errors leading to possible invalid inferences. Additionally, the standard Granger causality test fails to capture the time-varying essence of the causal nexus among the series. Its assumption of parameter stability does not allow the variation of the model parameters over time. On the other hand, when possible structural breaks exist, the model parameters indicate time variation (Perron, 2006). This highlights that considering the impact of possible structural changes and other nonlinearity forms with an appropriate methodology would make the provided inferences more reliable as they reveal the invisible forms in the data. In this vein, this study is expected to be beneficial for the body of the literature on this subject as it employs both the nonlinear and time-varying Granger causality methods and aims to investigate the nexus between the growth of the economy and carbon dioxide (CO2) emissions for Nigeria. As far as the authors are aware, no other researchers have attempted to examine the relation between these variables in Nigeria's context using nonlinear and time-varying methods. Hence, the main contribution of this research is that it aims to resolve the above-mentioned deficiency in the literature by providing better and more robust foresight for governors to plan and implement efficient and prudent policies to address the problem of climate change while maintaining economic growth.

The rest of this study's structure takes the following form: Sect. 2 deals with the methodology employed. Section 3 portrays the data and empirical outcomes, and finally, Sect. 4 presents the study's conclusion.

2 Methodology

In this study, in order to investigate the connection between the growth of the economy and the emissions of CO2, two different approaches are applied. This section briefly discusses the nonlinear Granger methodology in part one, while time-varying analysis is explained in the second part. Some preliminary tests are also adopted before utilizing the main methodologies. In Fig. 1, we show the schematic methodological flow.

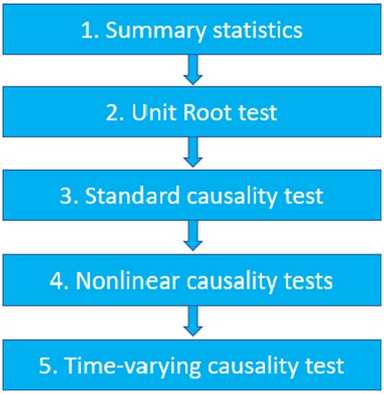

Fig. 1 A schematic methodological diagram

2.1 Nonlinear granger causality

To capture the nonlinear Granger causal flow, in addition to the linear test of Granger (1969), we have chosen to perform two additional tests in this section, namely Diks and Panchenko (DP, 2006) and Hiemstra and Jones (HJ, 1994). The linear (parametric) Granger causation test could inaccurately reveal the nature of the causality as a result of the relinquishing of nonlinearities. We can successfully deal with such limitations by considering the potential nonlinearities in the causality analysis through the two afore-mentioned nonparametric methods.

Hiemstra—Jones (1994) developed a nonparametric approach founded on the test for conditional independence developed by Baek and Brock (1992). For clarification of the HJ test, we first need to consider the two variables: $\{X_t\}$ and $\{Y_t\}$. The Granger causality test necessitates the detection of evidence opposing the null hypothesis ($\boldsymbol{H}_0$) such that, for example, "**$\{X_t\}$ does not Granger cause $\{Y_t\}$**".

Where limitations are not applied to the model, including the presumption that the process does not have a finite order, conditioning on the infinite past is not possible in the context of the nonparametric framework (Diks & Panchenko, 2006). Hence, $\{X_t\}$ and $\{Y_t\}$ are specified as lagged vectors of $= X_t^{l_x} X_{t-l_x+1}, \dots, X_t$ and $Y_t^{l_y} = y_{t-l_y+1}, \dots, Y_t$, respectively, with finite lag lengths equal to l_x and l_y. For finite lag lengths, the following test is defined for conditional independence.

$$(Y_{t+1}|X_t^{l_x}, Y_t^{l_y} \sim Y_{t+1}|Y_t^{l_y}) \tag{1}$$

Let $V_t = Y_t + 1$, $W_t = (X_t^{l_x}, Y_t^{l_y}, V_t)$ that is an $(l_x + l_y + 1)$-dimensional vector whose distribution is invariant. Here, with the aid of joint sequence ratios, the null hypothesis is determined. It displays the distribution of V_t when we have $(X, Y) = (x, y)$ is similar to the distribution of V when we have only $Y = y$.

$$\frac{f_{X,Y,V}(x,y,v)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \cdot \frac{f_{Y,V}(y,v)}{f_Y(y)} \tag{2}$$

In the above equation, we resemble $f_{X,Y,V}(x, y \mid v) = f_{X,Y}(x|y) = f_{Y,V}(y, v|v)$, which demonstrates the independent conditional impacts of X and V on $Y = y$, given the y can take any fixed value. It is possible to acquire the difference between Eq. (2) 's right and left sides by computing the ratios of correlation integrals expressed in the following:

$$\frac{C_{X,Y,V}(x,y,v)}{C_Y(y)} = \frac{C_{X,Y}(x,y)}{C_Y(y)} \cdot \frac{C_{Y,V}(y,v)}{C_Y(y)} \tag{3}$$

To ascertain the direction in which the Granger causality is running, we should calculate the correlation integrals defined for the sample in Eq. (3) followed by testing the statistical equality of the right- and left-hand side ratios.

$$C_{W,n}(\in) = \frac{2}{n(n-1)} \sum \sum l_{i,j}^{W} \tag{4}$$

where $l_{i,j}^{W}$ is equal to $I(\| W_i - W_j \| \leq \varepsilon)$. Diks and Panchenko (2005, 2006), in their reasoning, identified that the HJ test null hypothesis is misspecified, meaning that over-rejection of the null tends to occur. Resultantly, Diks and Panchenko (2006) multiplied Eq. (2) by a positive weight function, Q (x, y, v), so that the null of the HJ test is adjusted. By allowing Q $(x, y, v) = f_y^2$, the simplified Q can be displayed as:

$$\mathrm{Q} = \mathrm{E}\left[f_{X,Y,V}(X,Y,V)f_Y(\mathrm{Y}) - f_{X,Y}(X,Y)f_{Y,V}(\mathrm{Y},\ \mathrm{V})\right] \tag{5}$$

Having specified Eq. (5), through the application of the Diks and Panchenko process, it is possible to formularize the test statistic in the form of the following equation:

$$T_n\left(\in_n\right) = \frac{n-1}{n(n-2)} \times \sum_{i=1}^{n} \left(\hat{f}_{X,Y,V}\left(X_i, Y_i, V_i\right)\hat{f}_Y\left(\mathrm{Y}_i\right) - \hat{f}_{X,Y}\left(X_i, Y_i\right)\hat{f}_{Y,V}\left(\mathrm{Y}_i,\ \mathrm{V}_i\right)\right) \tag{6}$$

Here, ϵ_n denotes a bandwidth that shows dependence on the size of the sample n. An adequately elevated optimal bandwidth can be chosen to ensure that the estimates generated are efficient and consistent. Empirical applications following Diks and Panchenko (2006) usually restrict the bandwidth selection within the bounds [0.5, 1.5].

2.2 Time-varying approach

In this subsection, we explain the fully-fledged time-varying approach of Wang and Rossi (2019). The method is developed in a time-varying environment and is robust to the existence of different sources of instability. The time-varying VAR model with order p (VAR (p)) in a bivariate setup is defined as:

$$Z_t = \varphi_{1,t}Z_{t-1} + \varphi_{2,t}Z_{t-2} + \ldots + \varphi_{p,t}Z_{t-p} + \vartheta_t \tag{7}$$

Here, $\varphi_{k,t}$, $k=1,\ldots.p$ signifies the time-varying coefficient matrices and $Z_t = [X_t, Y_t]'$ is a vector of the variables under examination. ϑ_t indicates the assumed heteroskedastic and serially correlated idiosyncratic shocks.

In this method, for the purpose of testing the null of no causality ($H_0 : \rho_t = 0$) for all $t=1,\ldots T$, where ρ_t is a proper subset of $\{\varphi_{1,t}, \varphi_{2,t}, \ldots ..\varphi_{p,t}\}$, four different test statistics are considered: the exponential Wald (*ExpW*), Nyblom (*Nyblom*), mean Wald (*MeanW*), as well as Quandt Likelihood Ratio (*SupLR*). This technique requires an end-point trimming level, which in our study is selected as 5%. The method is performed in a VAR model of order 1, where p = 1 is selected by applying the Schwarz Information Criterion (SIC).

Table 1 Summary statistics

	Mean	Median	Max	Min	STD	Skewness	Kurtosis	JB
LCO2	– 0.25	– 0.12	0.01	– 0.79	0.23	– 0.92	4.38	43.69***
LG	1.87	1.88	1.96	1.76	0.06	0.01	3.61	22.08***

LG stands for the logarithmic form of the real GDP per capita, and LCO2 signifies the logarithmic form of CO2 emissions per capita. ***, denote significance at 1%

Table 2 Unit root results

	LEVEL				
	ADF	PP	DF-GLS	KPSS	ZA
LCO2	– 1.95	– 1.12	– 1.73	2.42***	– 3.44
LG	– 2.32	– 1.09	– 2.13	1.63***	– 3.76
First Differences					
LCO2	– 7.47***	– 8.72***	– 4.08***	0.09	– 7.87***
LG	– 6.33***	– 7.70***	– 6.02***	0.11	– 8.66***

According to the null hypothesis, the ADF, PP, ADF-GLS, and ZA tests show that the variables possess a unit root; in contrast, the null hypothesis of the KPSS test states the series is stationary. *** denotes a 1% level of significance

3 Data and empirical findings

In the context of our study, it could be argued that Nigeria does not have sufficient rich data available; thus, using different sources, accessible annual data for real GDP per capita and CO2 emissions were tabulated covering the timespan from 1950 to 2018. Real GDP per capita data were obtained from the Maddison Project Database (MPD) (2020), while the per capita CO2 emissions data were collected from the Our World in Data webpage.[1] In order to make adjustments to resolve the problem of dimensional differences among the series, each of the variables was converted into a logarithmic form. Following Shahbaz et al. (2018), the data were subsequently converted into quarterly series via the application of a quadratic match sum technique. The use of this approach enables the correction of seasonal variation of the data (Shahbaz et al., 2018).

The empirical analysis begins with the summary statistics of every series indicated in Table 1. The outcomes show that economic growth is right-skewed, while the log form of CO2 emissions is left-skewed. Moreover, both variables have fat tails, which lead to the non-normal distribution. This is reinforced by the fact that we can reject the null normality of the Jarque–Bera statistic at a one-percent significance level.

In the next part, the integration order of each series illustrated in Table 2 is examined. We apply several unit root tests, namely the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979), in addition to the semi-parametric unit root test (PP) developed by Phillips and Perron (1988), as well as the Augmented Dickey-Fuller

[1] Available at https://ourworldindata.org/

Table 3 Full sample linear Granger causality tests

	F-statistics	Asymptotic pval	Bootstrap pval
LCO2⇏LG	2.98	0.45	0.38
LG⇏LCO2	3.66	0.56	0.51

The displayed F-statistics are conducted utilizing a lag-augmented (VAR) model with order 1. The order of VAR ($p=1$) is chosen via the (SIC) Information Criterion, and bootstrap p values are obtained from 1000 replications

Generalized Least Squares (DF-GLS) test proposed by Elliot et al. (1996). Given that the conventional root tests are susceptible to a lack of reliability when possible structural break(s) are present, we also utilize the Zivot and Andrews (1992) structural break unit root test (ZA) to examine our unit root analysis' reliability. Additionally, we investigate the stationarity of the variables using the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test of Kwiatkowski et al. (1992) to cross-check our mean-reverting properties tests results.

As indicated by the conventional unit root test findings, it is obvious that both variables under examination have a unit root and their log levels are not mean-reverting. This finding is corroborated by the results of the KPSS and Zivot–Andrews tests; hence, the same integration order (i.e., I (1)) is concluded for both CO2 emissions and economic growth.

Subsequent to identifying the integration order of both variables, we now employ the conventional Granger causality test so that a comparison can be made. This method is constructed based on the full sample VAR model with order p (VAR (p)). Let us note that the optimal lag length is selected as $p=1$ for the VAR (p) model utilizing the parsimonious Schwarz Information Criterion (SIC). However, as the standard Granger methodology necessitates mean-reverting properties (Granger, 1969), the modified Wald (MWALD) test of Toda and Yamamoto (1995) is applied to examine the causal nexus among the variables. To enhance the Wald test statistics' power and make the results more robust in the present of unit root properties (see for more details; Hacker & Hatemi-J, 2006), we also consider the bootstrap distribution in addition to its formal asymptotic Chi-square distribution. The results are presented in Table 3.

As shown in Table 3, no evidence could be found showing a causal linkage for each pair of variables. The null hypothesis of non-causality cannot be rejected for each pair of variables at any conventional significance level. It should be noted that the above finding must be interpreted with caution, as the standard linear Granger test is biased when nonlinearity and structural breaks (that contradict the assumption of the constant parameters) are present. Many studies have shown that the parametric methods do not provide consistent and reliable results, as they suffer from the instability that arises from the existence of structural changes (Saliminezhad & Lisaniler, 2018). Hence, we continue to the next part of this study to evaluate the linear framework by employing the BDS test (independence test) developed by Brock et al. (1996) and the VAR model parameters' stability tests of Andrews (1993) and Andrews and Ploberger (1994).

In Table 4, the BDS test findings under the null of the iid residuals of the VAR (6) model are shown for each pair of series. It is clearly observable that we can reject the null of a linear dependency across all embedding (m) dimensions. This supports the hypothesis that a nonlinear link connects the variables. Therefore, we can statistically prove that the causal inferences according to the linear Granger test lack plausibility because they are subjected to invalidity when nonlinearity exists.

Table 4 Brock et al. (1996) BDS test

	M				
	2	3	4	5	6
VAR (1): [LG, LCO2]	0.000	0.000	0.002	0.000	0.000
VAR (1): [LCO2, LG]	0.000	0.000	0.000	0.000	0.003

Note: *m* denotes the amount of (embedded) dimensions, which embeds the time series within m-dimensional vectors, by using every m successive point within the series. The value within the cell denotes the BDS z-statistic's *p* value with the iid residuals null hypothesis

Table 5 Parameter's stability tests

	Sup-F	Mean-F	Exp-F
LC Equation	43.88***	16.25**	5.73**
LG Equation	21.02***	14.08**	6.45**
VAR System	65.47***	27.82***	16.65***

***and **illustrate significance at 1% and 5% levels, respectively. The p values are calculated utilizing 2,000 replications produced from the VAR (1) models with the parameters remaining constant (Andrews, 1993)

Table 6 Results of nonlinear causality test of Hiemstra and Jones (1994)

	m = 2		m = 3		m = 4	
	Test statistic	*p*-value	Test statistic	*p*-value	Test statistic	*p*-value
LCO2 $\nRightarrow$ LG	− 0.69	0.24	− 1.10	0.13	0.20	0.21
LG $\nRightarrow$ LCO2	− 0.98	0.12	− 1.20	0.11	0.72	0.19

m symbolizes the number of (embedded) dimensions. Results are presented with the bandwidth (ϵ_n) adjustment of 0.65

Table 5 displays the output of the VAR model parameters' stability tests. On the basis of three distinct statistics, namely Sup-F, Mean-F, and Exp-F of Andrews (1993) and Andrews and Ploberger (1994), one can see that each of the tests rejects the null of the parameters' stability. This implies that the VAR model parameters change across the sample horizon. Therefore, the inferences of the linear Granger causality are not reliable.

The evidence of the instability and the nonlinearity highlighted above motivates us to apply more robust frameworks. In this regard, as nonlinearity is present in the nexus of the variables, we investigate the nonlinear causation among the variables utilizing the nonlinear tests introduced by Hiemstra and Jones (1994) and Diks and Panchenko (2006). Given that these nonlinear methodologies require stationary variables, both series have been converted into the first-difference form (i.e., growth rates). In performing this stage, we use the robust order of the embedding dimension (*m*) of 2, 3, and 4 versus the applied lag order of one within the model (Further details are available in Diks & Panchenko, 2006). Both results are indicated in Tables 6 and 7, respectively.

Table 7 Nonlinear Granger causality test, Diks and Panchenko (2006)

	m = 2		m = 3		m = 4	
	Test statistic	*p*-value	Test statistic	*p*-value	Test statistic	*p*-value
LCO2 ⇏ LG	0.31	0.15	1.05	0.09	1.15	0.08
LG ⇏ LCO2	1.13	0.05	1.19	0.06	1.06	0.05

m symbolizes the number of (embedded) dimensions. Results are presented with the bandwidth (ϵ_n) adjustment of 0.65

Table 8 Time-varying parameter Granger causality tests

	ExpW	MeanW	Nyblom	SupLR
LCO2 ⇏ LG	40.17***	13.83***	3.56**	91.36***
LG ⇏ LCO2	64.73***	16.09***	41.25***	140.44***

The displayed statistics are conducted utilizing a time-varying VAR model with order 1. The order of VAR (p = 1) is chosen based on the Schwarz Information Criterion (SIC). *** and ** display significance at 1% and 5% levels, respectively

As shown in Table 6, the findings indicate that the null of non-causality between the variables cannot be rejected at whatsoever conventional significance degree. Surprisingly, a neutral effect for the CO2–growth nexus has been obtained in Nigeria through the HJ test.

The results of Table 6 suffer from the problem of over-rejection, as identified by Diks and Panchenko (2006). However, we adjust for this problem by applying the nonlinear test of DP depicted in Table 7.

The findings in Table 7 show the different inferences regarding the causal flow among the variables. This provides evidence indicating that a nonlinear causality flows from economic growth to CO2 emissions under all embedding cases. Contrastingly, the null of non-causality flowing from CO2 emissions to the growth of the economy can only be rejected under the embedding dimensions (m) of 3 and 4. Here, the evidence of dual causation between CO2 emission and output growth supports the feedback effect hypothesis and substantiates Mesagan's (2015) and Rafindadi's (2016) findings, while it contradicts those of Sulaiman (2014). The evidence of bidirectional casualties between the series can be further tested using the time-varying framework. It is important to check the validity of the results of our nonlinear tests in the presence of possible structural breaks. The country has clearly experienced substantial changes in rules and regulations in past decades, mainly with respect to energy issues. Therefore, this justifies the use of suitable methods to address the impact(s) of the structural changes.

As discussed earlier, the evidence of instability makes the full sample standard Granger causality unreliable. Thus, we apply the fully-fledged time-varying causality method proposed by Wang and Rossi (2019) to obtain valid inferences. This approach is robust in the presence of potential regime changes. It is built on the time-varying VAR model; hence, it allows the detection of exact periods of causal flows among the variables under examination. The four test statistics, namely *ExpW*, *MeanW*, *Nyblom,* and *SupLR* of Wang and Rossi (2019), are all reported in Table 8. Additionally, Figs. 2 and 3 show how the sequence of Wald test statistics for each direction varies over time. In both figures, the solid blue lines signify the Wald test statistics obtained from the time-varying VAR (1)

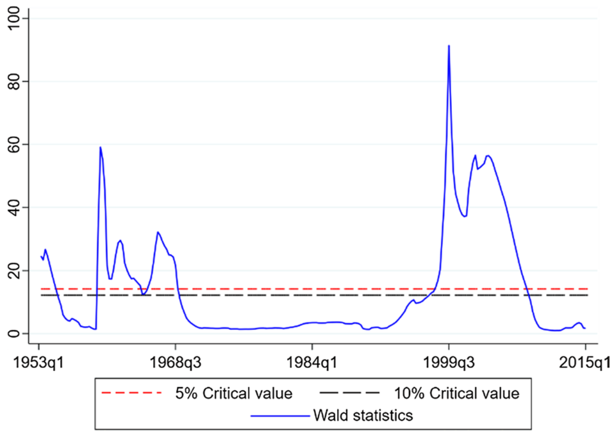

Fig. 2 Time-varying Wald statistics of VAR (1), verifying whether LCO2 Granger-causes LG

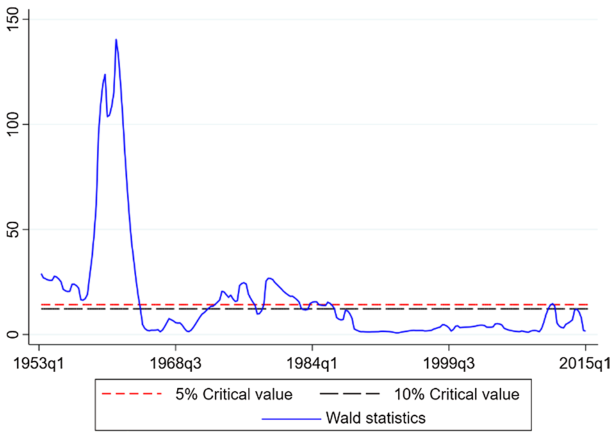

Fig. 3 Time-varying Wald statistics of VAR (1), verifying whether LG Granger causes LCO2

model, where the red- and black-dashed lines denote the 5% and 10% significance levels, respectively.

As shown in Table 8, the null of no Granger causality in both directions can be overwhelmingly rejected across all four test statistics. This highlights the strong time-varying evidence of predictability of CO2 emissions for economic growth and, likewise, the growth level for CO2 emissions. Similar to the nonlinear findings, here we also can support the feedback effect hypothesis between the growth of the economy and the emissions of CO2 in Nigeria.

The Wald test statistics pattern indicated in Figs. 2 and 3 supports evidence of the causality flows' strong time-varying nature. As can be clearly seen in Fig. 2, barring the middle part of the sample period, the evidence strongly indicates a causal flow from CO2 emissions to economic growth for the other parts.

However, in Fig. 3, robust indications of a causal flow from economic growth to CO2 emission are roughly detected in the early part of the sample to the late-1980s.

Evidence showing a bidirectional linkage between the economy's growth and carbon emissions implies that protecting the environment may reduce the economic growth of Nigeria, a country with a population of about 170 million. There is no doubt that in Nigeria, energy is the cardinal means of a achieving a higher and veritable growth level. At the same time, due to inefficiencies in its usage, it is known as the main contributor to CO2 emissions (Sulaiman & Abdul-Rahim, 2018). Thus, the trade-off between seeking a higher growth level and mitigating environmental concerns is an ongoing controversial issue. However, this struggle could be easily resolved if the relevant authorities in the country consider using a more appropriate supply mix. This can be attained by developing a suitable roadmap to provide larger room for cleaner energy sources resulting in a higher efficiency level. Using more renewable energy sources along with the development of a strategic energy efficiency approach, as discussed in the Nigerian National Renewable Energy Action Plan (NREAP), will ultimately helping the country to reduce CO2 emissions while maintaining sustainable economic growth. Our results highlight the need to carefully implement this plan as it plays a significant role in lessening Nigeria's energy predicament by advancing renewable energies. The country has significant potential for clean energy sources through crops and fuelwood, biogas, wind, solar, and hydro; however, they are largely underused. A substantial number of advanced nations with similar resources have focused on renewable energy. Hence, executing any course of action that will incite reasonable and sustainable energy improvement as a backbone of climate control and economic development in Nigeria is crucial.

Here, it is worth mentioning that the results obtained in this study, as directed by our objective, are based on the utilization of nonlinear and time-varying methodologies, which have not been addressed in the related literature for the case of Nigeria. However, there is a possibility of applying the other available nonlinear methods to examine the association between the variables. The nonparametric quantile Granger causality test would be a good option for application (Bahramian & Saliminezhad, 2020). Although this method can robustly capture the nonlinearities, it lacks the consideration of their time-varying linkages. As our aim was related to assessing the variables' links in both nonlinear and time-varying environments, we did not use the quantile-based method, and it can be further considered for a future research agenda.

4 Conclusion

Significant evidence shows that environmental degradation can potentially impose particular effects on economic activities, and Nigeria is no exception to this phenomenon. Given this issue and the unavailability of robust empirical works in this area, this study aimed to test the causal relationships between CO2 emissions and economic growth utilizing more well-grounded approaches. Using the full linear sample Granger causality method, no evidence of causal flows has been detected among the variables. However, given the established instability and nonlinearity encompassed in the variables' linkages, the findings of more robust methodologies of nonlinear and time-varying Granger causality suggest different inferences about the causal linkages between the emissions of CO2 and the growth of the economy.

Our findings indicate that nonlinear time-varying bidirectional causality linkages exist between the examined series in Nigeria. This provides valuable evidence for policymakers who are seeking more significant insights into the relationship between the series. The main implications of these outcomes can be divided into two parts. First, in policy terms, it infers that reducing CO2 emissions and improving environmental quality are restricted at the expense of output growth. The lack of energy efficiency in a country like Nigeria, which is significantly dependent on carbon-based fuels, can be reduced by using more green energy sources, mainly at the industrial level. The higher contribution of the clean energy resources in the country's energy paradigm will enable Nigeria to achieve a win–win situation in which both environmental concerns and sustainable development can be adequately addressed. This study's second recommendation further emphasizes that nonlinear and time-varying interactions between the variables should be modeled via appropriate methodological approaches to provide robust inferences for adopting and planning appropriate energy and environmental policies.

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