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Research Article

Mediating role of stock market volatility to evaluate asymmetries in the growth-degradation nexus in Nigeria

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Abstract. This study explores the mediating role of stock market volatility in the economic growth and environmental degradation nexus in Nigeria using data covering period from 1984 until 2020. The study uses Nonlinear Autoregressive Distributed Lag (NARDL) and a nonparametric asymmetric causality model. While the Wald test in model 1 reveals evidence of weak long-run asymmetric nexus between CO_2 and economic growth however, findings in model 2 indicates that stock market volatility (SMV) exerts a strong asymmetric effect in growth-CO_2 relation in the long-run. The result of nonlinear model validates the inverted U-shaped growth-degradation nexus consistent with EKC hypothesis. The finding in model 1 reveals that investment exerts a strong impact on CO_2 in both the short-run and long-run. On the other hand, the results in model 2 show that the positive component of economic growth has a positive and significant impact on CO_2 in Nigeria. However, the negative component of economic growth has a negative impact on CO_2. Moreover, the dynamic causality model reveals: (i) a feedback causality between CO_2 and the negative component of GDP; and (ii) a unidirectional causality flowing from CO_2 to the positive component of GDP. Similarly, result of nonlinear causality test reveals a feedback causality between CO_2 and GDP. The implication of the finding suggests that while asymmetric properties of economic growth must be controlled in efforts of promoting environmental sustainability, the stock market has a dedicated role to play in widening access to funds for green investment in Nigeria and other developing economies.

Keywords: CO_2 Emission, EKC hypothesis, Nonlinearity, Stock Volatility, Environmental Sustainability

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1. Introduction

The last four decades have witnessed a rapid increase in environmental challenges all over the globe, where Nigeria inclusive are among the major contributor to greenhouse gas emissions (GHGs). A greater percentage of this environmental degradation is attributable to increased human activities and over-exploitation of the resource base (Ibrahim, 2022). These economic activities have not only a strong impact on environmental quality but also premised the development of the celebrated Environmental Kuznets Curve (EKC hereafter) hypothesis (Anwar *et al.* 2022). The EKC hypothesis posits that environmental damage deepens with a sustained increase in income reached a turning point at a particular level of income and declines (Stern, Common & Barbier, 1996; Gessesse and He, 2020).

There are several transmission mechanisms through which an increase in economic activities can affect GHGs, particularly CO_2 emissions. Grossman and Krueger (1991) point out three possible channels: the scale effect, technological effect and composition effect. It is argued that the scale effect has often a negative consequence on the environmental quality via the intensity of production. As productive activities which involve the use of natural resources upsurge, the depletion of resources spreads faster than resource regeneration. In this way, pollution and CO_2 emissions would increase rapidly. On the other hand, composition and technological effects have strong positive consequences on the performance of the economy (Abid *et al.* 2022). This is made possible by the rapid economic development which results in structural improvement leading to energy switching from conventional energy-intensive industries to cleaner services (including renewable energy) this can be achieved through abatement activities as well as research and development (Mehmood *et al.* 2021) which invariably improve environmental quality.

Avalanche of literature has identified several measures of environmental degradation ranging from urbanisation, ecological footprint, load capacity factor, waste per capita, and capital emission of CO_2 to SO_2 concentration (Ibrahim and Tanimu, 2016; Cavusoglu *et al.* 2019; Oladipupo *et al.* 2022). Various regressions analyses have also been used in empirical modelling of the $C0_2$-growth nexus with moderating effect of per capita income, investment, political rights, electrical tariff, debt per capital, civil liberty, financial development, trade openness, and per capita income (Abid *et al.* 2022; Anwar *et al.* 2022). In particular, Farooq *et al.* (2021) have convincingly found that per capita income has always shown a strong impact on the various

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measures of environmental factors. It is therefore assumed that as per capita income moved beyond the EKC turning point, the structural transition to improve environmental quality begins to take effect.

Numerous empirical studies have highlighted the trade-off between rapid increased in economic activities and sustainable environmental quality (see, for instance, Aliero and Ibrahim, 2012; Anwar *et al.* 2022; Cavusoglu *et al.* 2019). Stern *et al.* (1996) have particularly found that greater economic activities often retarding the environmental quality at the initial stage as static assumptions about technology, environmental investment and tastes. These factors in reality are the salient determinants crucial in influencing the environmental impact of every increase in economic activity. The implication of this is that the asymmetries in the CO_2-growth nexus cannot be evaluated in isolation. In the same vein, several empirical studies provide strong evidence that stock market development serves as an important determinant of environmental quality (Tamazian, Chousa and Vadlamannati 2009; Cetin and Ecevit 2017).

Moreover, stock market development has strong asymmetric properties that often-triggered market volatility. Several studies have argued that stock market volatility can impede the acceleration of economic activity by affecting the incentive to save (Gani and Ibrahim, 2015). This may invariably hamper the structural changes that will bring about the transition to environmental-friendly activities. Based on this insight, it is imperative to consider the effect of abrupt changes in stock market returns in exploring EKC hypothesis. Another point of inflexion is that available studies utilize a symmetric approach while examining the dynamics of growth-degradation (Cetin and Ecevit 2017; Farooq *et al.* 2021 Isiksal *et al.*,2019, Zhao *et al.*,2023 Pata and Samour,2023 Pata and Samour, 2022; Kartal *et al.*,2023 Adebayo and Samour, 2023). Moreover, Adebayo *et al.* (2021) pointed out that it is inappropriate to empirically model a single equation to estimate the dynamic of growth-environment relation with a faulty assumption of unidirectional causality between economic growth and environmental degradation. Modelling a single equation in presence of simultaneity will lead to biased, bogus and inconsistent estimates (Cavusoglu *et al.* 2019).

Utilization of environmental resources devoid of the principle of sustainability may reduce the environmental regenerating capacity. The environmental resource-base has an assimilative capacity. Once this capacity is exceeded, any further increase in pollution-generating activities can be harmful to humans, reduces the availability and productivity of available resources (Saliminezhad, Ozdeser and Birnintsaba, 2022), and in turn interferes with the environmental life support services (Mehmood *et al.* 2021). On empirical accounts, Anwar and Elfaki (2021) have used rich data to validate the EKC paradigm taking into cognisance of the rising level of deforestation and pollution which increasingly affect human health and not the production possibilities. This means that validation of EKC will ultimately maximize production and improve the quality of life in poor countries. Selden and Song (1994) observed that the declining ambient pollution does not necessarily reflect a decrease in aggregate emission because as society develops, the population densities in the urban settlements go through rising and falling processes and the level of emission also goes through the same process. To clarify this asymmetric tendency, it is important to employ nonlinear causal techniques that are efficient in capturing the asymmetric causality of environmental degradation and economic growth.

Moreover, available empirical studies both time series, country-based studies, and panel studies depend largely on linear relationships and mostly assumed a unidirectional relationship flowing to environmental degradation (see Ozturk and Acaravci 2013; Gani and Ibrahim, 2015; Samour *et al.*,2019; Cetin and Ecevit 2017).). These studies also concentrated more on the symmetric relationship when in fact, the EKC hypothesis assumed an asymmetric pattern in the degradation-growth relation. The asymmetric dynamics in the growth-CO_2 nexus have been partially explored, particularly in the Nigerian context. This study intends to contribute to the literature dealing with environmental issues on three important questions: Is there asymmetries in the economic growth and environmental degradation relation? What is the nonlinear causality between CO_2 and economic growth? Does stock market volatility make any difference in the growth-environment nexus? Answering these questions will unravel how asymmetries are shaping the growth-environment nexus, particularly after controlling for stock market shocks.

The present study builds on existing studies and fills a lacuna in the extant empirical literature addressing environmental issues in three ways. First, several studies have explored growth-degradation dynamics mainly by imposing some restrictive assumptions to satisfied the linearity conditions. It remains plausible that regime transition and environmental regulation could induce cyclicality in the CO_2-growth relation which could possibly invalidate the linearity assumption. Nonlinearity in series can lead to specification error in the standard linear framework (such as the traditional Granger causality model) which increases the likelihood of making a wrong inference. Although Saliminezhad *et al.* (2022) have made a novel attempt to model the nonlinear properties of the $C0_2$-growth nexus, however, their study has failed to apply a nonlinear unit root test which would have helped establish econometrically whether nonlinearity exists in the series or not. This study addresses this issue by applying Kapetanios, Shin and Snell (hereafter, KSS) (2003) unit root in the exponential stationary smooth transition autoregressive (ESTAR) framework which paved way for determining the variables that exhibited asymmetric patterns. Secondly, the inverted U-shaped assumption of EKC points to an element of dynamism in the conditional distribution of the variables. This renders the conventional ARDL model inadequate given the asymmetric pattern of the variable(s). As such, a novel NARDL proposed by Shin *et al* (2014) is adopted in the decomposition of the variable of interest into positive and negative components. This will give a wide range of policy options based on the dynamic decomposed multipliers that will help in ameliorating the adverse effect of economic growth on environmental sustainability. Third, the stock market in developing counties has recently been repositioned to serve as an important source of green finance. This could facilitate structural changes that will bring the needed transition towards renewable energy and green technology. Extant studies have not addressed this issue in greater detail, especially in the context of recent efforts of Nigeria to reduce its reliance on crude oil by embracing more renewable energy. This study has controlled for the effect of stock market volatility in the CO_2-growth nexus via a wide range of econometrics techniques that support the reduction of environmental degradation through policies that promote green investment.

2. **Literature review**

2.1 Theoretical settings

Kuznets (1954) used an inverted U-shape curve to advance a theory that explains the correlation between per capita income and inequality. The theory hypothesises that as per capita income of individuals increases; social inequality widens at the initial stage until it gets to a turning point where income

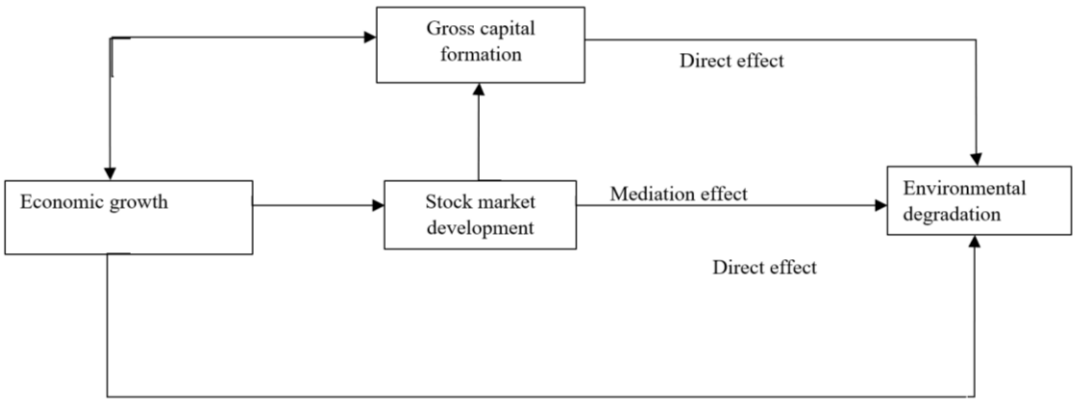


Fig. 1. Mediation effect of stock market in environmental degradation and economic growth relation

inequality declines with a further increase in income. The EKC thus predicts an inverted U-shape in the CO_2-growth nexus where at a certain point the negative impact of increased economic activities on the environmental quality diminishes rapidly (Dinder, 2004; Abid *et al.* 2022). Kuznet's (1954) inverted U-shaped curve became the foundational stone for the EKC hypothesis which underpins the novel work of Grossman and Krueger (1991). Several studies have found that various indicators of environmental quality improve as income and consumption improve (Ibrahim and Gani, 2015; Farooq *et al.* 2022; Saliminezhad *et al.* 2022). The EKC hypothesis refutes the general belief that environmental degradation is limited to advanced countries that are burdened with industrialization (Cavusoglu *et al.* 2019).

Theoretically, rapid economic growth that relies on conventional energy can retard environmental quality. To achieve economic growth, developing countries rapidly engaged in industrialization policy whereby new investments for the needed capital are funded partly by the stock market (see Fig. 1). The theoretical bases for the dynamic growth-gradation relation have attracted several empirical studies which can be broadly classified into three. The first validates EKC, the second established energy consumption and production whilst the third combines the two (Alvarado and Toledo 2016). Meanwhile, Stem *et al* (1996) criticized the EKC hypothesis based on its limited application to different types of environmental factors. They pointed out that biodiversity loss is irreversible and may cause severe negative secondary effects and they suggested that EKC will be less applicable in a situation where the turning point stretched to the extent that the secondary effect arises. However, some economists believe that EKC is enshrined in the endogenous growth model encapsulating the roles of technological advancement and capital allocation in shaping the pattern of economic development consistent with the environmental protection and abatement activities (Gani and Ibrahim, 2015), hence, the decline in environmental degradation (Dinder, 2002).

2.2 Empirical Literature

Several empirical literatures have raised several empirical conclusions about the validity of EKC. The differences in findings can be attributed to countries' specific idiosyncratic factors, time differences, and differences in measures of environmental degradation. Shafik and Bandyopadhyay's (1992) empirical result showed ambiguous feedback between growth and environmental quality leading to raising a possibility of growing out of the environmental problem. They however argued that the progress is gradual because actions are taken only when there is a generalized local cost and substantial social and private benefits. The Grossman and Krueger (1994) examined the effect of SO_2 dark matter on the environmental sustainability in Mexico. The finding shows element of asymmetries as economic growth improves environmental quality at the middle-income level, and decreases environmental quality at high income. Moreover, Tamazian *et al.* (2009) investigated the effect of economic growth and financial development (FD) on environmental pollution in BRIC by employing a panel regression technique. The result reveals that economic growth and FD decreases environmental pollution. Shahbaz *et al.* (2011) investigated the nexus among energy consumption (EC), economic growth and CO_2 in Pakistan. The bound cointegration test results reveal a long-run inverse nexus between FD and CO_2. Employing the Granger causality test, Ozturk and Acaravci (2013) explored the causality between CO_2 and economic growth with augmented roles of trade openness (TO) in the case of Turkey. The finding revealed that there is a unidirectional causality running from FD to CO_2. Shahbaz, Tiwari and Nasari (2013) tested the EKC for South Africa using data on coal consumption, TO, CO_2 emissions and economic growth. The study reveals not only a strong impact of FD on $C0_2$ emissions but also a unidirectional causality running from $C0_2$ emissions to FD.

Moreover, Shahzad *et al.* (2014) utilized the ARDL bounds test, Fully Modified Ordinary Least Square, and Dynamics Ordinary Least Square to explore the impact of economic growth and EC on environmental sustainability for Pakistan and found long-run bi-directional causality the variables. By employing simultaneous-equation panel data models, Omri *et al.* (2015) explore the dynamic impact of FD, renewable energy and CO_2 on economic growth in 12 MENA countries. The results of GMM indicate a strong negative effect of FD and CO_2 on growth in Jordan and a positive strong effect in Qatar. Alvarado and Toledo (2016) examine the growth-degradation nexus for some developing country. Their results show that there exists an inverse relationship between vegetal cover and real GDP. Cetin and Ecevit (2017) investigated the EKC hypothesis within a framework of structural break. The study found a positive correlation between economic growth and $C0_2$ in the presence of structural break. Moreover, Vo and Ho (2021) explored growth-degradation relation using threshold VAR for Vietnam. Their study confirms the inverted U-shaped between economic growth and carbon emission. Saliminezhad *et al.* (2022) investigated the causal direction between CO_2, renewable energy and the growth using both nonlinear and a novel time-varying causality model. The results revealed bidirectional causality between GDP and CO_2.

Based on the foregoing discussion of literature, there exists a sizable number of empirical studies that investigated various factors that influence environmental sustainability such as economic growth, financial deepening and conventional energy consumption, renewable energy amongst others. However, researchers that control for nonlinearity in the data are limited. Besides, the role of stock market volatility in the CO_2-growth nexus is partially explored. Despite the increasing recognition of the key roles of the stock market in financing green investment and renewable energy. Thus, this paper made attempts to contribute to the literature by filling this lacuna in the environmental and economic sustainability nexus.

3. Methodology

3.1 Data and model specification.

This paper utilizes annual data retrieved from world development indicators and Central Bank of Nigeria's (CBN) statistical bulleting spanning from 1984 until 2020. Following empirical studies of Abd *et al.* (2022) and Saliminezhad *et al.* (2022), this study augmented the EKC hypothesis by using CO_2 per capita emission, GDP per capita, and Gross Fixed Capital Formation (GFCF). The stock market volatility (SMV) series is generated based on the procedure described by Levine and Zervos (1996) and Jude (2009). The SMV is measured as a 12 month rolling standard deviation estimate based on the all share index (ASI) of the Nigerian Stock Exchange. We smoothen the process through autoregressive conditional hetroscedasticity (ARCH) procedures and then generates SMV series using generalised autoregressive conditional hetroscedasticity. This study set to explore the CO_2 – growth nexus with mediating effect of SMV. To achieve this objective, the primary functional form of the model is specified as Eq 1:

$$CO_2 = f(GDP_t, GFCF_t, SMV_t) \quad (1)$$

Two models are specified based on equation (1) with the first is the baseline model that explores the CO_2 – growth nexus while the second model controls for the effect of SMV in the context of CO_2-growth relation. The empirical form of the models is stated as Eq 2 and 3:

$$lnCO_2 = \beta_0 + \beta_1\, lnGDP_t + \beta_2\, lnGFCF_t + \epsilon_t \quad (2)$$

$$lnCO_2 = \beta_0 + \beta_1 lnGDP_t + \beta_2\, lnGFCF_t + \beta_3\, lnSMV_t + \varepsilon_t \quad (3)$$

Where *t* is the period operator, β_i represent the parameters of the variables while ϵ_t and ε_t denote stochastic error term.

3.2 Estimation strategy

This study set to mediate the effect of SMV in the asymmetric relationship growth-degradation nexus consistent with EKC hypothesis. As a prerequisite for estimating time series in models, we first conduct Augmented Dickey-Fuller (ADF), and Philips Perron (PP) tests to ascertain the unit root properties of the series as specified in Equations (4) and (5).

$$\Delta Wt = \Upsilon + \beta W_{t-1} - \sum_{j-1}^{p} \alpha j\ \Delta Wt - j + \varepsilon_t \quad (4)$$

$$\Delta z_t = y + \psi_{tz_{t1}} + \varepsilon_{2t} \quad (5)$$

The study also applies the Zivot and Andrew's (1992) structural break-based unit root tests to test for a single structural break in the series based on intercept and trend are specified in Equations (6) to (8) respectively.

$$\Delta x_t = \theta_0 + \theta_1 + \lambda x_{t-1} + \beta DU_t + \sum_{j=1}^{k} \delta_j \Delta x_{t-j} + \varepsilon_t \quad (6)$$

$$\Delta x_t = \alpha_0 + \alpha_1 + \lambda x_{t-1} + \gamma DT_t + \sum_{j=1}^{k} \delta_j D x_{t-j} + \varepsilon_t \quad (7)$$

$$\Delta x_t = \varphi_0 + \varphi_1 + \lambda x_{t-1} + \beta DU_t + \gamma DT_t + \sum_{j=1}^{k} \delta_j D x_{t-j} + \varepsilon_t \quad (8)$$

Where DU_t is the dummy variable which indicates the mean shift that occurs at each possible breakpoint (T_j^b). Similarly, the mean shift in the trend variable is denoted by DT_t. The hypothesis is stated in the null such that $H_0: \theta = 0$. The alternative hypothesis is $H_1: \theta < 0$. $DU_t = 1$ if $t > T_j^b$ and 0 if otherwise. In the same vein, $DT_t = t_{T_j^b}$ if $t > T_j^b$, and 0 if otherwise. Consequently, the null hypothesis of $H_0: \theta = 0$ denotes a unit root in the presence of one breakpoint. Whereas, the alternative of $H_1: \theta < 0$ indicates the absence of unit root at one break point.

Since the crux of this study is to estimate the mediating effect of SMV in the asymmetric (nonlinear) relationship between environmental degradation and growth, it will be biased to draw conclusions relying on symmetric unit root tests. To this end, this study applied the KSS nonlinear unit root test based on Monte Carlo ESTAR model. The ESTAR model is specified in equation 9.

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left(1 - exp\left(-\theta y_{t-d}^2\right)\right) + \epsilon_t \quad (9)$$

To examine the asymmetric cointegration nexus between CO_2 and economic growth, this study applied the NARDL proposed by Shin *et al.* (2014). The NARDL is efficient in terms of power and size in estimating pure I(1) variables or combination of I(0) and I(1) covariates. In additionally, the NARDL can generate the error correction term as well as long-run and short-run dynamics that could aid policymaking aimed at achieving environmental sustainability.

The application of the NARDL model requires that the ARDL is first estimated based on the Eq 10:

$$\begin{aligned}\Delta LCO_2 = {} & \sum_{i=1}^{q} \beta_{i1} \Delta LCO_{2_{t-1}} + \sum_{i=1}^{q} \beta_{2i} \Delta LGDP_{t-1} + \sum_{i=1}^{q} \beta_{3i} \Delta LGFCF_{t-1} \\ & + \sum_{i=1}^{q} \beta_{5i} \Delta LSMV_{t-1} + \alpha_1 LCO_{2_{t-1}} + \alpha_2 LGDP_{t-1} \\ & + \alpha_3 LGFCF_{t-1} + \alpha_4 LFDI_{t-1} + \alpha_5 LSMV_{t-1} \\ & + \varepsilon_t \end{aligned} \quad (10)$$

Where Δ represent the difference operator, β's represent short-run and long-run coefficients are derived through normalizing $\alpha_2 - \alpha_5$ on α_1. p is the lag-length parameter whilst ε represents the random stochastic disturbance term.

The ARDL bound test is estimated with a null hypothesis of no cointegration ($H_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$) using F-statistics as a metric of testing for joint significance is tested against the alternative of cointegration or inconclusive result.

Pesaran *et al.* (2001) proposed two bounds viz upper bound I(1) and lower bound I(0) which are tested against the computed F-statistics. The null hypothesis of no cointegration is if the values of the lower bound are higher than the F-statistics at a 1%, 5% or 10% level of significance. On the other hand, the alternative hypothesis of cointegration is accepted if the F-statistics is higher than the upper bound values at either 1%, 5% or 10% level of significance. The result is declared inconclusive if the values of *F*-statistics fall between the lower and upper bound.

Since the objective of the study is to determine the asymmetries in the growth-degradation relation, it is pertinent to determine if the impact of GDP negative (economic scale effect) is statistically different from GDP positive (composition and technological change effect). Based on this conjecture, we decomposed GDP into positive and negative components as specified in Equation (11).

$$GDP_t = GDP_t^- \mp GDP_t^+ \quad (11)$$

The decomposition defined as $GDP_t^- = \sum_{i=1}^{t} \Delta GDP_t^- = \sum_{i=1}^{t} \min(\Delta GDP_t, 0)$ and $GDP_t^+ = \sum_{i=1}^{t} \Delta GDP_t^+ = \sum_{i=1}^{t} \max(\Delta GDP_t^+, 0)$.

In equation (11), GDP_t^- denotes the negative change in GDP growth. it is considered that growth at this level is detrimental to environmental quality due to the scale effect. The economic activities at this stage erode environmental quality through carbon emission. On the other hand, GDP_t^+ represents the positive regime where the economy has grown enough to invest in abatement activities that improve environmental quality.

If GDP_t in equation 2 is replaced with GDP_t^- and GDP_t^+ components, the asymmetric ARDL is given as:

$$\Delta CO_2 = \delta_t + \sum_{i=1}^{q} \gamma_{i1} \Delta CO_{2_{t-1}} + \sum_{i=1}^{q} \gamma_{2i} \Delta LGDP_{t-1}^- + \sum_{i=1}^{q} \gamma_{3i} \Delta LGDP_{t-1}^+ + \sum_{i=1}^{q} \beta\gamma_{4i} \Delta LGFCF_{t-1} + \sum_{i=1}^{q} \gamma_{5i} \Delta LFDI_{t-1} + \sum_{i=1}^{q} \gamma_{6i} \Delta LSMV_{t-1} + \theta_1 CO_{1i_{t-1}} + \theta_2 LGDP_{t-1}^- + \theta_{3i} LGDP_{t-1}^+ + \theta_{4i} LGFCF_{t-1} + \theta_{5i} LFDI_{t-1} + \theta_{6i} LSMV_{t-1} + \varepsilon_t \quad (12)$$

Equation 12 presents the short-run and long-run asymmetric effect of economic growth on environmental degradation. γ's and θ's represent the coefficients of short-run and long-run effects respectively. To test for the asymmetries in the growth-CO_2, the procedure of Bahmani-Oskooee and Fariditavana (2015) and Li and Guo (2022) which includes computing a Wald test was used to determine the magnitude of a negative and positive effect of economic growth on the environment. The decision rule is to reject the null hypothesis of symmetric relationship if the negative component is statistically different from that of the positive component that is if

$$\sum_{i=1}^{q} \gamma_{2i} \neq \sum_{i=1}^{q} \gamma_{3i}$$

It means that there exists a short-run symmetric effect of economic growth on environmental degradation. However, the null hypothesis of long-run symmetric is rejected if $-\frac{\theta_{2i}}{\theta_1} \neq -\frac{\theta_{3i}}{\theta_1}$. The next procedure after the short-run and long-run asymmetric relationship has been established is to compute the multiplier effect of both positive and negative effects of economic growth on environmental degradation. Following Shin *et al.* (2014), we generate the multiplier effect m_b^- and m_b^+ associated with the negative and positive asymmetric effect of economic growth and environmental degradation from equation 13 as follows:

$$m_b^- = \sum_{i=1}^{b} \frac{\delta CO_{2_{t+1}}}{GDP_{t-1}}, \quad m_b^+ = \sum_{i=1}^{b} \frac{\delta CO_{2_{t+1}}}{\delta GDP_{t-1}} \quad where\ b = 0,1,2 \quad (13)$$

It is worthy to note that as $b \to \infty, m_b^- \to \theta_{2i}$ and $m_b^+ \to \theta_{3i}$ and $m_b^+ \to \theta_{3i}$ where θ_{2i} and θ_{3i} are the long-run parameters associated with the negative and positive effects of economic growth respectively.

The causality for linear model will be explored within the framework of Toda and Yamamoto's (TY, 1995) causality test. This test is an alternative procedure of testing the causal effect based on the modified non-causality test. It is employed in this study because the conventional causality test is fragile when variables are not stationary. The result generated from such a process may not be robust because in such a case the resulting test statistics do not follow a normal distribution order. To overcome this, TY proposed a simple procedure for estimating an augmented VAR which is based on $k + d_{\max}$ [f0] and generates asymptotic Wald statistics in form of the chi-square distribution. TY encompasses all manners of VAR conditions that is, it is applicable regardless of VAR integrating order or cointegrating form. The procedure includes the determination of maximum order of integration, $d_{\max}$ and suitable lag length, k free from serial correlation. To test for serial correlation at the optimal lag, the Langrage Multiplier is performed. AR root test is then used to test for the stability of the VAR. the VAR is stable if no root lies outside the 5% significance circle. The TY model is specified as follows;

$$In\, X_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i}\, InY_{t-1} + \sum_{j=k+1}^{d} \alpha_{2j} InY_{t-i} + \sum_{i=1}^{k} \delta_{2j} In\, X_{t-j} + \sum_{j=k+1}^{d} \delta_{2j} InX_{t-1} + \varepsilon_{2t} \quad (14)$$

$$In\, X_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i}\, InX_{t-1} + \sum_{j=k+1}^{d} \beta_{2j}\, InX_{t-i} + \sum_{i=1}^{k} \theta_{2j}\, In\, Y_{t-j} \sum_{j=k+1}^{d} \delta_{2j} InY_{t-1} + \varepsilon_t \quad (15)$$

The Wald statistics are obtained when *p*th order VAR in equations (14) and (15) are estimated based on an asymptotic X^2 distribution with k degree of freedom. The null hypothesis of Granger non-causality is rejected if the probability of X^2 distribution is significant.

On the other hand, this study examines nonlinear causality by adopting the Dicks and Panchenko (2006) nonparametric asymmetric causality model. The general form asymmetric model is specified by Eq 16:

$$T_n(\epsilon_n) = \frac{n-1}{n(n-2)} \times \sum_{i=1}^{n} \hat{f}_{X,Y,V}(X_i, Y_i, V_i) \hat{f}_y(Y_i) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,V}(Y_i, V_i) \quad (16)$$

with T_n denotes test statistics based on the sample size n, and ϵ_n denotes bandwidth that is dependent on the sample size *n*. It is worthy to note that an optimal bandwidth can be chosen to ensure efficient and consistent estimates. In this way, Ibrahim and Sanusi (2022) posited that empirical applications using this process usually restrict the bandwidth selection within the 0.5 and 1.5 bounds.

4. Empirical results and discussion

4.1 Descriptive statistics

The descriptive statistics of the variables are presented in Table 1. The standard deviation shows the link between the data and sample average. The kurtosis measures the peaks of the distribution of the series, whereas skewness measures the degree of asymmetries of the series. The results in Table 1 show that GDP, CO_2, and SMVL have minimum values lower than

Table 1
Descriptive statistics

Variables	GDP	CO_2	SMV	GFCF
Mean	1796.023	89001.39	0.009566	5.46E+10
Median	1598.820	85870.00	0.007209	5.39E+10
Maximum	2550.470	134612.7	0.051494	7.58E+10
Minimum	1317.360	42441.86	0.005547	3.75E+10
Std. Dev.	450.0639	19100.44	0.006515	9.35E+09
Skewness	0.426967	0.510615	4.008256	0.246233
Kurtosis	1.497430	3.115016	22.06453	2.361565
Jarque-Bera	18.04597	6.380852	2601.967	3.927827
Prob.	0.000121	0.041154	0.000000	0.140308

Table 2
Unit root test results

Variables	ADF		Integration	ZA unit root with structural break		
	ADF	PP		Break in intercept	Break in trend	Break in intercept & trend
$\ln GDP$	-0.718	-0.674		-3.152 (2008)	-2.610 (1994)	-4.182 (2002)
$\Delta\ln GDP$	-3.717**	-3.611***	I(1)	-2.731 (2000)	-2.024 (2010)	-3.878 (2002)
$ln\,C02$	-1.634	-1.314		-4.171 9 (1998)	-4.048 (2013)	-4.625 (1998)
$\Delta\,ln\,C02$	-9.293***	-14.511***	I(1)	-7.621*** (1997)	-6.674** (2000)	-6.532* **(2001)
$lnLSMV$	-4.305***	-4.305***	I(0)	-5.525** (2011)	-5.198** (2010)	-5.487*** (2011)
$\Delta lnLSMV$	-	-	-	-5.844** (2010)	4.917 (2010)	5.715***(2010)
$lnGFCF$	-0.572	-1.423		-4.071 (2001)	-3.112 (2014)	-4.935* (2001)
$\Delta lnGFCF$	-9.172***	-10.441***	I(1)	-9.460*** (2001)	4.809 (2001)	-6.033*** (2001)

Notes: ADP, PP, and ZA refers to Augmented Dickey Fuller, Phillips Perron and, Zivot and Andrew, respectively.
**, ***indicates statistical significance at 5% and 1% level respectively.

their respective average values whereas GFCF has a minimum value greater than its average value. The descriptive statistics show elements of asymmetries in the distribution of the data, with the GDP and GFCF are symmetrical around their respective mean as against CO_2 and SMV that possess elements of asymmetries as shown by their skewness values. Similarly, GDP GFCF are platykurtic which implies that the distribution curve is flat. Meanwhile, CO_2 is mesokurtic and SMV shows a leptokurtic distribution.

4.2 Unit root test

Table 2 displays the results for evaluating the stationary of variables using ADF, PP and ZA. The results of ADF and PP show that GDP, CO_2 and GFCF are not stationary at their level and have a unit root, but they are stationary at the first difference (Δ) affirming that the series are I(1). As explained in section 3 that SMV was generated using GARCH from ASI series. This ASI is I(1) variable but the generated SMV is stationary at the level which confirm with theory which state that the residual of the generated series must be independently and identically distributed (Cavusoglu *et al*. 2019). On the other hand, Zivot-Andrew unit root test, as depicted in Table 2, show that all variables are I(1) with their respective break date.

The asymmetric unit root test is reported in Table 3. The results of the KSS unit root reveal that the null hypotheses of unit root are not rejected for GDP, $C0_2$ and GFCF at level. However, their null hypotheses were rejected at the first difference which indicate that the variables are I(1). Conversely. The SMV is I(0) as the null hypothesis of unit root of the variable is not rejected at level. Having mixture of I(0) and I(1) variables satisfied the condition for asymmetric analysis within the framework of NARDL.

4.3 Cointegration test results

As highlighted in section 3 that an ARDL will be estimated as a pre-requisite for estimating the NARDL. The results of bound test as stated in Table 4 show that F_{ARDL} for the two linear models are higher than the critical upper bound values, I(1) indicating the evidence of cointegration among the variables. The results of F_{NARDL} provide sufficient evidence on the existence of nonlinear cointegration among GDP, CO_2, GFCF and MSV variables which points to the existence of asymmetric causality among these co-moved variables at least in one direction.

The finding asymmetric cointegration in the growth-degradation relation is consistent with EKC hypothesis. The finding validates the theoretical conclusion of Salinminezhad *et al*. (2022) which raises the prospect of asymmetries in $C0_2$-growth relation. The result also reinforces the finding of Samour *et al*. (2019) which reveals cointegration relation between environmental quality and economic growth of Turkey.

Table 3
Kapetanios, *et al*. (2003) nonlinear unit root test

Variables	Level	First diff	Asymmetric
$\ln GDP$	0.339	-5.144***	Yes
$ln\,C02$	-1.406	-3.117**	Yes
$lnLSMV$	-3.352**		Yes
$lnGFCF$	0.983	-2.961**	Yes

**, ***indicates statistical significance at 5% and 1% level respectively.

Table 4
The results of ARDL and Nonlinear ARDL test for cointegration

Models	F_{ARDL}	F_{NARDL}	$I(0)$	$I(1)$
$lnCO_2 = f(lnGDP_t, lnGFCF_t)_{ARDL}$	6.66**	-	3.88	4.61
$lnCO_2 = f(lnGDP_t, lnGFCF_t)_{NARDL}$	-	5.39**	3.38	4.23
$lnCO_2 = f(lnGDP_t, lnGFCF_t, lnSMV_t)_{ARDL}$	5.71**	-	3.05	4.23
$lnCO_2 = f(lnGDP_t, lnGFCF_t, lnSMV_t)_{NARDL}$	-	6.67**	3.05	3.97

**indicates statistical significance at 5% level.

4.4 The asymmetric dynamics

There are two procedures for testing asymmetric relationships based on the extant literature: long-run and short-run asymmetries. Given that the evidence of nonlinear cointegration is found in this study, the asymmetric relation among the variables are tested within long-run asymmetric model. The empirical results for asymmetric tests for the two main models are shown in Table 5. The null hypothesis of no asymmetry is not rejected for model 1. However, the null hypothesis of no asymmetry is rejected for Model 2 as the asymptotic Chi-square statistics generated by the Wald test is found to be statistically different from zero. This result implies that stock market volatility plays a vital role in the asymmetric growth-CO_2 relation in the long-run. Consequently, stock market volatility is a major factor that exerts asymmetric effect on economic activities at a different level of growth which will lead to environmental degradation consistent with the EKC hypothesis.

Table 5
Test for Long-run asymmetries for the models (Wald Test)

Models	Wald test	X^2 Statistics
Model 1	W_{LR1}	0.6409
Model 2	W_{LR2}	4.6743**

Note: ** denotes 5% level of significance. W_{LR1} and W_{LR2} Represent model 1 and model 2 long-run asymmetries respectively.

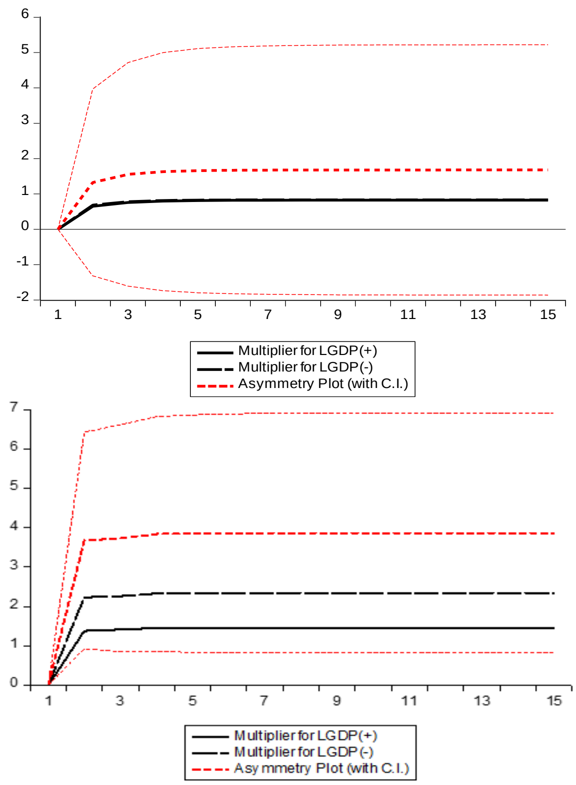


Fig. 2. Asymmetric graphs for model 1 and 2.

The study further computes the asymmetric multipliers for the two alternative models as shown in Figure 2. The first panel of Figure 2 confirms the absence of an asymmetric relationship for model 1 as the line of positive and negative effects converge to form a single line. However, panel 2 of the Figure 2 confirms the presence of an asymmetric relationship. The red dotted line that represents the asymmetry plot in panel 2 behaves similarly to the negative and positive effect in which it rises to a particular point and stretches, remaining constant. This plot suggests that both the scale effect of the enhance economic growth (negative effect) and the impact of an increase in abatement activities (positive effect) on environmental degradation may be felt to a particular point where the further increase in both activities remain constant.

4.5 NARDL short-run and long-run results

The NARDL estimated output of short and long runs dynamics is reported in Table 6. The finding in model 1 indicates that investment (GFCF) is an important determinant of environmental degradation in the short and long runs. Interestingly, the impact of investment on environmental degradation is highly elastic in the long run (1.47) whereas is less elastic in the short run (0.398). This finding can be explained by the fact that Nigeria is increasingly focus in sourcing for long-term investable funds consistent country's growth drive. These investments are not green compliant which raises demand for conventional energy, deepens the countries energy crisis and exacerbates environmental degradation. This finding is consistent with the recent studies of Gessesse and He (2020) in China; Mehmood *et al.* (2021) in ASEAN countries; and Vo and Ho (2021) in Vietnam, Omri *et al.* (2015) in MENA countries, and Ozturk and Acaravci (2013) in Turkey

Model 2 of Table 6 considers the mediating effect of SMV in the C02-growth relation. The results show that the positive component of economic growth, which captures the composition and technological effect, has a positive and significant impact on CO_2 in Nigeria. However, the negative component of economic growth has a negative impact on CO_2. This result implies that Nigeria and indeed other developing countries need to implement a wide range of policies that transform their economy into green and renewable which will facilitate the transition of composition and technological component of growth into the path that will improve environmental quality consistent with turning point of EKC as highlighted in Kernel density in Fig 3 (a). The growth drive of successive government in Nigeria has led to sustained increased in the energy consumption (energy intensity) which increases the GHGs and exacerbating the degradation of environment. This is consistent with the graphical result of which lends credence to the EKC hypothesis that level of degradation increases with growth, reaches the turning point and decreases, as highlighted in the Kernel density in Fig. 3(a). On the other hand, the scale effect which captures the energy transition from conventional to renewable energy ought to have triggered the turning point and make the environmental improvement. However, with risen energy poverty affecting Nigerian economy

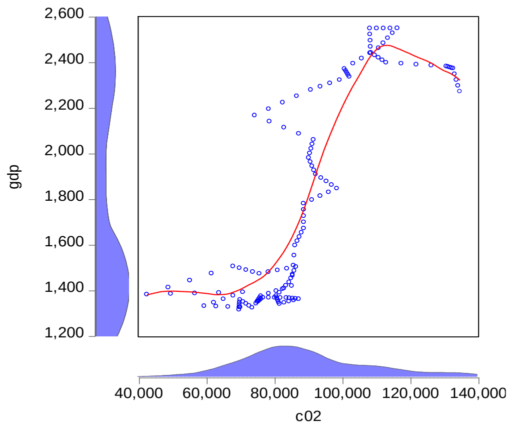
Table 6
NARDL long run and short run dynamics

	Model 1		Model 2	
Variables	Coef.	Prob.	Coef.	Prob.
$\ln GDP_{pos}$	0.830	0.277	1.415**	0.033
$\ln GDP_{neg}$	-0.779	0.580	-2.352*	0.061
$lnGFCF$	1.470**	0.032	1.117**	0.033
$lnSMV$			-0.243*	0.006
$@Trend$	-0.031	0.347	-0.049	0.071
$\Delta lnGFCF$	0.398**	0.041	0.297	0.069
$\Delta lnGFCF\ (-1)$	-0.582**	0.048	-0.527	0.003
$\Delta lnSMV$			-0.137*	0.002
ECT_{t-1}	-0.827*	0.000	-0.971	0.000
Diagnostic tests				
JG	0.0861(0.917)		10.77(0.004)	
BG	0.086 (0.917)		0.665(0.524)	
$ARCH$	14.366(0.368)		2.213(0.146)	
$RESET$	0.0002(0.9883)		0.227(0.822)	

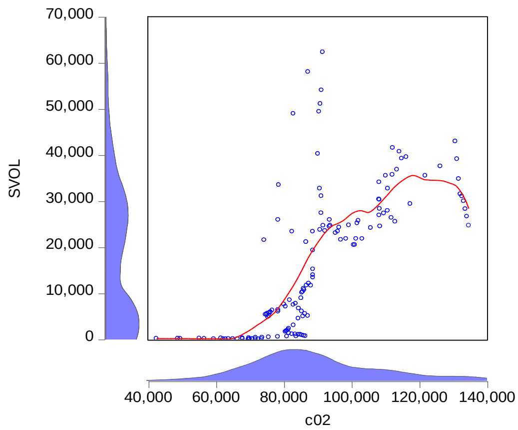
Note: *,** and *** denote 1%, 5% and 10% level of significance respectively; ( ) represent probability values; S.E: standard error regression; JB Jarque-Bera statistics for residual normality; BG: Breusch-Godfrey Serial correlation LM test; ARCH: Autoregressive Conditional Heteroscedasticity test; RESET: Residual error specification test.

which necessitate the manufacturing sector to heavily relied on conventional energy source (such as generators) couple with the aftermath the implementation of economic recovery and growth plan (ERGP) in 2017 as a strategy of converting economic recession have jointly worsened the environmental problems in the country, consistent with the environmental decay in EKC.

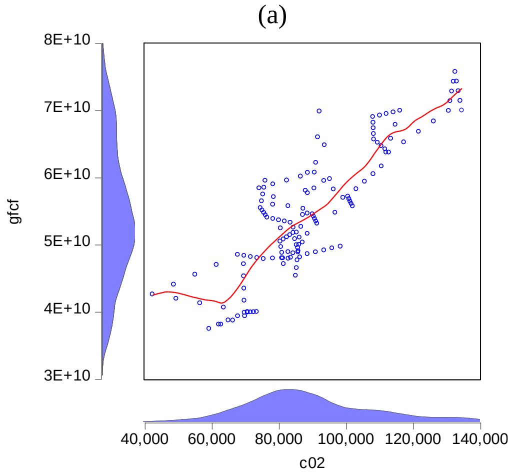
The green bond policy implemented to drive the development of stock market has been encouraging the green investment paving the way for the sustained use of renewable energy. As such, stock market is inverting the asymmetry in the CO_2-growth nexus which made possible the attainment of turning point and asymmetric decrease of CO_2 based on kernel density in Fig. 3(b) than in Fig. 3(a). The findings further indicate that the coefficient of SMV in both the short and long run is negative and statistically significant at the 1% level. Numerically, a 1% increase in stock market financing will decrease environmental degradation by 24% and 13% in the long run and short run, respectively. Interestingly, the impact of GFCF remains negative even after controlling for SMV. The graphical result in Fig.3(c) indicates the evidence of EKC in pollution-investment nexus for Nigeria. This implies that investment and stock market volatility are strong determinants



(a)



(b)



(c)

Fig. 3. Empirical EKC of Nigeria indicating (a)Pollution-Growth nexus; (b) the Pollution-SVOL nexus; (c) the Pollution-Investment nexus

Fig 4. (a) Stability test: CUSUM for model 1;(b) Fig. 4(b). Stability test: CUSUM Sq. for model 1,(c) Stability test: CUSUM for model 2; (d) Stability test: CUSUM Sq. for model 2; (e) NARDL Stability test: CUSUM for model 1;(f) NARDL Stability test: CUSUM Sq. for model 1;(g) NARDL Stability test: CUSUM for model 2;(h) NARDL Stability test: CUSUM Sq. for model 2

of environmental degradation in Nigeria which is in line with the finding of Gessesse and He (2020) and that of Salinminezhad *et al*. (2022).

Regarding the coefficients of error correction models, the results reveal that the coefficients of ECT_{t-1} for Models 1 and 2 are negative and significant at the 1% level, which indicates that there are convergences along the long-run equilibrium in the event of distortion in the short-run. These results validate the preceding results which demonstrated the long run relationship among economic growth, investment, stock market volatility

Table 7
TY causality test result

Panel A: causality from other variables to LCO2			
Variables	Dependent variable: LCO_2		
	Chi-sq	Df	Prob.
LGDP_NEG	11.04140*	1	0.0009
LGDP_POS	0.058453	1	0.8090
LGFCF	0.025028	1	0.8743
LSMVOL	1.895339	1	0.1686
Panel B: causality from LCO2 to other variable			
Independent variable: LCO_2			
LGDP_NEG	2.970625***	1	0.0848
LGDP_POS	11.64707*	1	0.0006
LGFCF	0.000562	1	0.9811
LSMVOL	1.735727	1	0.1877

Note:* and *** denote 1% and 10% level of significance respectively.

and environmental degradation. Approximately 82% and 97% of distortions in environmental quality are corrected by the deviations from short run to the long run path for Model 1 and Model 2, respectively.

The diagnostic check shows that the two Models are free from serial correlation evident in BG probability and are homoskedastic as revealed by the ARCH test. The Models are adequately specified as shown by the RESET test. The plots of stability in form of cumulative sum (CUSUM) of recursive residuals and cumulative sum of square (CUSUM of Square) of recursive residuals for all the models are shown in Fig 4(a) to 4(h) indicating that the models are stable which implies that estimated models are robust, consistent and the findings are reliable.

4.6 Causality test results

The TY causality test results are presented in Table 7. The results are displayed in Panels A and B. Panel A shows the flow of causality from other variables to carbon emission while Panel B presents the flow of causality from CO_2 to other variables. The finding reveals that there is bidirectional causality between CO_2 and the negative component of economic growth whereas a unidirectional causality flows from CO_2 to GDP was found. This result provides an evidence on the existence of inverted U-shape EKC hypothesis for Nigeria.

On the other hand, the results of the nonlinear Granger causality test implemented with the methodological framework of Diks and Panchenko (2006) are presented in Table 8. The test statistics indicate a bidirectional causal relation between CO_2 and GDP, SMV and GDP, GFCF and GDP and SMV and GFCF. This finding reinforces a strong asymmetric causal relation between GDP and CO_2 in Nigeria. This result supports the finding of Saliminezhad *et al* (2022). The result further indicates a unidirectional causality runs CO_2 to GFCF and CO_2 to SMV. This implies that environmental degradation can be reduced through investment, especially green investment that will stimulate clean energy and stock market can play a dedicated role in sourcing funds for green investment.

5. Conclusion

This paper examines the mediating role of stock market volatility in the testing asymmetries on growth-degradation nexus based on the EKC hypothesis in Nigeria. The study finds evidence of the existence of nonlinear cointegration among GDP, CO_2, investment and SMV. Furthermore, our results demonstrate the existence of a strong asymmetric causality between GDP and CO_2 in Nigeria. The findings also reveal that investment is a significant driver of environmental degradation both in the short run and the long run. Both the linear and nonlinear causality result revealed that there is feedback causality between environmental degradation and economic growth. Interestingly, stock market volatility plays a vital role in driving the asymmetries in the growth-degradation relation. The empirical result validates the EKC hypothesis positing that

Table 8
Results of Diks and Panchenko (2006) asymmetric causality test

Causal Settings		***Inferences***
$ln(C0_2) \nrightarrow ln(GDP)$	$ln(GDP) \nrightarrow ln(C0_2)$	
1.488*	1.930***	Bidirectional
$ln(C0_2) \nrightarrow ln(GFCF)$	$ln(GFCF) \nrightarrow ln(C0_2)$	
1.901**	0.259	Unidirectional
$ln(SMV) \nrightarrow ln(GDP)$	$ln(GDP) \nrightarrow ln(SMV)$	
1.448**	1.930***	Bidirectional
$ln(SMV) \nrightarrow ln(C0_2)$	$ln(C0_2) \nrightarrow ln(SMV)$	
0.648	1.479*	Unidirectional
$ln(GDP) \nrightarrow ln(GFCF)$	$ln(GFCF) \nrightarrow ln(GDP)$	
1.901***	1.514*	Bidirectional
$ln(SMV) \nrightarrow ln(GFCF)$	$ln(GFCF) \nrightarrow ln(SMV)$	
1.839***	1.677***	Bidirectional

Note: $\nrightarrow$, symbolizes no causal linkge. Results are obtained using 2 to 4embedded dimension and a bandwidth of 0.532. The number is cells stand for the corresponding test statistics.
*,**, ***indicates statistical significance at 10%, 5% and 1% level respectively.

economic growth reaches a turning point where further growth improves environmental quality. In this sense, it can be argued that factors that influence environmental degradation must be adequately taken into consideration when drafting policies aim at reducing environmental degradation. Since there is feedback between GDP and CO_2, it means that production possibilities may be compromised, therefore regulations that ensure that production is maximised with minimal effect on the environment should be enacted.

Based on the foregoing, the stock market must be repositioned to play a dedicated role of supporting the reduction of environmental degradation through policies that promote green investment and investment in renewable energy, which has far lower emissions than fossil fuel. In this way, the regulatory body must be strengthened to put in place strategies that enhance investors' confidence which will help in reducing stock market volatility and open windows for green financing of investment in clean energy that will not jeopardise environmental quality, hence, improve the indices of economic growth and development in Nigeria.

The implication of this study lies on the consequential role of the government of Nigeria in enacting policies and providing enabling environment for investors to confidently engage resources in long-term investments which is the surest path to economic growth devoid of environmental degradation. This is because clean and renewable energy requires long-term investment which can better be garnered through the mechanism of stock market.

Future research can improve on this study by including other factors such as monetary and fiscal policies that can potentially harm the environment and militate against technological and composition effects which are expected to bring about improvement in the environmental quality.

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