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Is economic growth a remedy for environmental degradation in oil-producing countries? New evidence from Africa

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ABSTRACT

The debate on the possibility of economic growth improving the quality of the environment has yet to reach a consensus. To contribute to this debate, we investigate the validity of the Environmental Kuznets Curve (EKC) hypothesis for oil-producing countries in Africa based on annual data from 1991 to 2019. We also examine the causal relationship between environmental quality and economic growth. The panel autoregressive distribution lag (PARDL) technique and the Granger non-causality test were employed. The findings show evidence of an inverted U-shaped relationship between economic growth and environmental quality in the long run, indicating the validity of the EKC hypothesis. It was also observed that energy prices exert strong, deteriorating effects on the environment in the short run. In the long run, renewable energy consumption and energy prices significantly improve the quality of the environment. The Granger causality test results demonstrate a unidirectional causality from environmental quality to economic growth. It was concluded that policies aimed at improving environmental quality in these countries could be beneficial in the short run. In the long run, these policies will prove beneficial only when economic growth is at a level where the quality of the environment is declining, since economic growth improves environmental quality.

Contribution/Originality: This study contributes to the literature by exploring the potential of economic growth to address environmental degradation in Africa's oil-producing countries in the short and long runs. In addition, it offers insights into the causal relationship between economic growth and environmental degradation in these countries.

1. INTRODUCTION

In the 1990s, increasing concern among the public regarding the widespread environmental deterioration drove efforts to understand the dominant cause of this degradation. During that time, it was uncertain whether or not economic growth was consistent with improvements in the environment (Dinda, 2004). Attempts aimed at comprehending the nexus between economic growth and environmental quality brought about the Environmental Kuznets Curve (EKC) concept and the reversed U-shaped connection between economic growth and the fall in the quality of the environment (Karsch, 2019). Grossman and Krueger (1991) proved that the association between pollutants (e.g., smoke and carbon dioxide) and per capita gross domestic product (GDP) has an inverted U-shaped. This was after Kuznets (1955) detected a reversed U-shaped association between economic growth and income inequality. Many studies have emerged since Grossman and Krueger (1991) that examine the presence of the EKC hypothesis (Bennedsen, Hillebrand, & Jensen, 2023; Bulut, 2021; Cho, Chu, & Yang, 2014; Deacon & Norman, 2006; Ike, Usman, Alola, & Sarkodie, 2020; Kisswani, Harraf, & Kisswani, 2019; Mahmood, Alkhateeb, & Furqan, 2020; Nazir, Nazir, Hashmi, & Ali, 2018; Proops & Safonov, 2004; Rana & Sharma, 2019; Shahbaz, Solarin, Hammoudeh, & Shahzad, 2017; Sinha Babu & Datta, 2013; Stern, 2004; Stokey, 1998; Zhang, Chen, & Yu, 2023) and Rock and Herbst (2023).

The EKC posits that as a country becomes more economically advanced, the quality of its environment deteriorates as a result of rising energy usage; however, once the country achieves a particular level of economic stability, the quality of its environment improves (Bennedsen et al., 2023; Grossman & Krueger, 1991; Proops & Safonov, 2004; Rana & Sharma, 2019). The idea behind the reversed U-shaped association between economic growth and the quality of the environment is that the early-stage production structure of a country progresses from a conventional, pollution-intensive industrial economy to a more environmentally friendly, service-oriented economy (Dinda, 2004; Shin, Yu, & Greenwood-Nimmo, 2014). It's worth noting that growth in human capital is an important element in the EKC. Pata and Caglar (2021) argue that human capital growth comes with the following: (1) improved energy security and a better understanding of environmental issues; (2) the capability to mitigate environmental pollution through implementing cutting-edge technologies; (3) the preference for renewable energies and ecological food sources and the willingness to pay carbon taxes; and (4) lower energy output per unit and, therefore, reduced energy intensity.

The EKC hypothesis suggests that economic growth will ultimately improve the quality of the environment (Stern, 2004). That is to say, at lower incomes, environmental degradation should increase, attain a maximum (its turning point), and then decline at higher incomes (Hu, 2006). The implication is that economic growth can be a key strategy for enhancing the quality of the environment in developing countries, enabling them to grow economically out of environmental problems (Sinha Babu & Datta, 2013). If the EKC hypothesis is valid, it implies that there will be an automatic improvement in the quality of the environment, even when nothing is done to improve it (Cho et al., 2014). Thus, proponents of the EKC contend that it is not necessary to be concerned about reversing environmental harm caused by economic growth. The reason is that environmental damage attributable to economic growth can always be repaired since economic growth is compatible with improvements in environmental quality. This has been demonstrated by highly industrialized nations (Bennedsen et al., 2023; Vanli, 2023). According to Deacon and Norman (2006), the existence of the EKC hypothesis has the following implications: Income growth is accompanied by an increase in pollution in low-income countries; in middle-income countries it increases first, then declines; and in high-income countries it falls.

The reversed U-shaped link between income and environmental quality could emerge from not putting pollution control measures in place until a population threshold is reached (Stokey, 1998), naturally in the Solow growth model (Brock & Taylor, 2005), and resulting from rising returns to scale reducing pollution (Andreoni & Levinson, 2001). The present study evaluates the EKC hypothesis for oil-producing countries in Africa by examining the effect of factors that influence environmental quality. Investigating the validity of the EKC hypothesis in these countries is crucial because, if valid, these countries will be confident that with environmental policies in place, economic growth will only be a threat to their environment for a limited period; thereafter, the environmental quality should improve. The findings provide insight into the nature of the association between economic growth and the quality of the environment for oil-producing countries in Africa, thereby directing environmental policies and future planning regarding the environment.

The remaining part of this paper is set out as follows: Section 2 presents a review of the relevant literature, Section 3 discusses the methodology, Section 4 contains the results and analysis, and Section 5 comprises the conclusion and policy implications.

2. LITERATURE REVIEW

Literature on the nexus between economic growth and the environment reveals that the former affects the latter via three channels: (1) The scale effect, which suggests that a rise in economic activities worsens environmental quality since an increase in output requires the use of more inputs (sourced from the environment), which reduces the quality of the environment; (2) The composition effect, which proposes that a country's production composition changes as it achieves higher growth (Bouvier, 2004). Here, a country's production structure changes from agriculture to manufacturing and is associated with the degradation of the environment and then a decline in manufacturing activity, paving the way for the expansion of services, thereby improving the quality of the environment; (3) The technique effect, which is a decline in environmental degradation or improvement in environmental quality brought about by technological improvement (Chen, Shi, & Wang, 2020).

Several studies have investigated the EKC hypothesis, the findings of which have not reached a consensus. Some studies validate the hypothesis, but other studies found no evidence to validate it. Diverse factors, including the type and number of variables included in a model, the methodology employed, proxies for environmental degradation, the number of countries included, and the time period covered, are responsible for the lack of unanimity in the findings of those studies. This literature review looks at some of these studies on the EKC hypothesis, starting with those that authenticate the proposition, followed by the studies that do not validate it.

Nazir et al. (2018) assessed the validity of the EKC hypothesis for Pakistan from 1970–2016. They employed the autoregressive distributed lag (ARDL) bound test approach and reported evidence to support the EKC hypothesis. Similarly, Ike et al. (2020) applied the panel cointegration test to annual data from 1970–2014 for G7 countries and confirmed the existence of the EKC hypothesis at country-specific and panel levels. They also reported that the volume of trade exerts a positive effect on CO_2 emissions and detected evidence of negative impacts of energy prices on CO_2 emissions at the country-specific level. Mahmood et al. (2020) utilized the spatial autoregressive (SAR) model and yearly data from 1990–2014 to uncover the energy consumption, income, trade, and foreign direct investment (FDI) impact on CO_2 emissions for Egypt, Algeria, Morocco, Libya, and Tunisia and observed evidence of the EKC hypothesis. A similar finding was also reported by Zhang et al. (2023) for East Asia and Pacific countries after applying the dynamic common correlation effects and the pooled mean group (PMG) to yearly data covering 1995–2020.

In assessing the causality associations between economic growth, FDI, and CO_2 emissions and with trade (imports and exports) levels in the context of India over the 1982–2013 period, Rana and Sharma (2019) used the dynamic multivariate Toda–Yamamoto Granger causality test to provide evidence of the presence of both the pollution haven hypothesis (PHH) and the EKC hypothesis. Bulut (2021) documented evidence of the EKC hypothesis but not for the PHH for Turkey after applying the ARDL and dynamic ordinary least squares (DOLS) models to annual data for the period from 1970–2016 to detect ecological footprint determinants within the EKC hypothesis scope. For the 1996–2002 period in China, the findings of Hu (2006) provide evidence of the EKC hypothesis. Rock and Herbst (2023) also provide results supporting the validity of the EKC for Poland by employing the spatial lag model technique.

Haider, Bashir, Husnain, and Muhammad (2020) checked for the presence of the EKC hypothesis for the top 15 countries ranked based on N_2O emissions and the highest 18 nations ranked based on the share of agriculture of the GDP from 1980–2012. By employing the pooled mean group (PMG) approach, their findings support the presence of the EKC hypothesis. Islam, Shahbaz, and Butt (2013) applied the Granger causality test, the vector error correction model (VECM), and the ARDL technique to annual data spanning from 1971–2010 for Bangladesh and detected evidence that supports the EKC hypothesis. In the UK, Vanli (2023) applied the VECM and ARDL techniques to yearly data from 1949–2018 and observed that, in the long run, the EKC hypothesis is valid. Charfeddine and Mrabet (2017) utilized the fully modified ordinary least squares (FMOLS), DOLS, and annual data spanning from 1975–2017 in 15 countries in the Middle East and North Africa (MENA). Their findings revealed that GDP per capita has an inverted U-shaped association with the ecological footprint in countries that produce oil, suggesting that the EKC hypothesis is valid. Likewise, Bennedsen et al. (2023) found evidence of the EKC hypothesis in the context of OECD countries from 1960–2018 based on the fixed effects and the network regression component.

Cheikh, Zaied, and Chevallier (2021) utilized the nonlinear panel smooth transition regression (PSTR) framework and annual data spanning from 1980–2015 for 12 MENA countries and reported inverted U-shaped evidence for the impact of GDP per capita on CO_2. Cho et al. (2014) evaluated the association among CO_2 emissions, energy use, and GDP for 22 OECD countries using annual data from 1971–2000. They employed the FMOLS method and reported findings that support the EKC proposition. By using yearly data from 1980–2013 and panel dynamic ordinary least squares (PDOLS) to investigate the linkages and causality directions between FDI, energy use, economic growth, and CO_2 emissions for nine MENA countries, Gorus and Aslan (2019) found evidence that supports the EKC proposition and the PHH. Malik et al. (2020) applied the ARDL and non-linear ARDL techniques to yearly data for Pakistan from 1971–2014. Their results confirmed the EKC hypothesis; the symmetric results show that economic growth contributes to CO_2 emissions in the short and long runs. Tiba and Frikha (2019) applied panel FMOLS and DOLS to annual data from 26 African countries covering the period from 1990–2016 and provide evidence for the presence of the EKC proposition.

However, some studies fail to support the EKC hypothesis. For instance, Kisswani et al. (2019) investigated if the EKC hypothesis exists in five countries of the Association of Southeast Asian Nations (ASEAN 5). The data spans from 1971–2013, and the ARDL model and PMG results provide no evidence to support the EKC. Similarly, Moutinho, Madaleno, and Elheddad (2020) employed panel corrected standard errors (PCSE) and yearly data from 1992–2015 to investigate the EKC in 12 countries of the Organisation of Petroleum Exporting Countries (OPEC). Their results indicate the existence of a U-shaped relationship, indicating that economic growth in these countries increases environmental degradation, contrary to the assertion of the EKC proposition. Pata and Caglar (2021) also reported a U-shaped connection between environmental pollution and income level for ecological footprints and CO_2 emissions in China. This suggests a lack of evidence for the EKC after examining the influence of income on ecological footprint, human capital, globalization, renewable energy usage, and trade openness using yearly data from 1980–2016 and an augmented ARDL model. In addition, they reported that income drives environmental pollution.

To examine the validity of the EKC proposition and the factors that drive CO_2 emissions in Kenya, Nigeria, Egypt, the Congo, and South Africa, Lin, Omoju, Nwakeze, Okonkwo, and Megbowon (2016) utilized the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT), and the FMOLS techniques, and annual data covering 1980–2011 and reported no evidence to validate the EKC hypothesis. Zambrano-Monserrate, Silva-Zambrano, Davalos-Penafiel, Zambrano-Monserrate, and Ruano (2018) used yearly data from 1980–2011, the ARDL model, and the VECM to analyze the association between CO_2 emissions from energy usage, GDP, renewable electricity utilization, dry natural gas consumption, and total petroleum consumption in Peru to assess the EKC hypothesis. They found no evidence to support the EKC. Furthermore, they documented that the elasticity of CO_2 emissions in the long run to a change in economic growth is greater than the short-run elasticity, implying that CO_2 emissions are associated with a higher level of income. Sinha Babu and Datta (2013) modelled the association between environmental degradation and economic growth using yearly data from 1980–2008 for 20 developing countries. The fixed effects (FE) regression model estimates showed that for most of the countries, the nexus between economic growth and environmental degradation is N-shaped.

The literature search revealed that, although the EKC hypothesis has been extensively investigated, it has not been investigated for oil-producing countries in Africa. We, therefore, investigate the EKC hypothesis and assess the causal link between environmental quality and economic growth, squared (nonlinear) economic growth, renewable energy usage, energy price, imports, exports, financial development, and capital formation for oil-producing countries in Africa. Previous studies have employed diverse methodologies to evaluate the EKC hypothesis in many countries. The approach in this paper, however, deviates significantly from that of previous studies. This research only uses the increase in economic growth; that is, we investigate the validity of the EKC hypothesis based on the rise (positive change) in income growth. To determine the increase in economic growth per capita series, we decompose the GDP per capita series into two, viz., the increase and decrease series, and use only the increase series. The reason for decomposing and using only the rise in GDP per capita series is that the EKC hypothesis is postulated based on the impact of an increase in income per capita over time on the quality of the environment. Using the per capita GDP series (which comprises both increases and decreases) may result in biased estimates. By using the increase series, we overcome these biases, thereby presenting more accurate results, enabling us to better measure how environmental quality is affected by income per capita in the sampled countries. In time series prediction, using decomposing series leads to more accurate results (Armstrong, Green, & Graefe, 2015).

To the best of our knowledge, only Ongan, Isik, and Ozdemir (2021) examined the validity of the EKC hypothesis using an increase in per capita income for the US. Our study differs significantly from Ongan et al. (2021) since it is a panel study on developing, oil-producing countries. Panel data analysis offers numerous benefits over time series data analysis. They provide more precise inferences of model parameters, simplify computation and statistical inference, have a greater ability to capture human behavior complexities than a cross-section or time series study,[1] and allow researchers to better understand the dynamics of adjustment because many economic relationships are dynamic.[2] This paper contributes to the existing body of knowledge in the following ways: First, it investigates the effect of economic growth on environmental quality in the short and long; second, it assesses the influence of renewable energy consumption, imports, exports, energy prices, financial development, and capital formation on short- and long-run environmental quality; and third, it examines the causal association between the quality of the environment and the regressors of the model, i.e., economic growth, squared economic growth, oil price, renewable energy consumption, capital formation, and financial development.

3. METHODOLOGY

3.1. Data and Data Description

This is a panel data study for 20 African oil-producing countries from 1990–2019. The Appendix provides a list of all the countries selected for the study. Our regressand is environmental quality, represented by CO_2 emissions per capita in metric tons, which is consistent with the literature, while our predictor variables are economic growth and nonlinear economic growth. We proxy economic growth with real GDP per capita in local currency. We generate positive and negative changes in GDP per capita and use only the positive changes (increases). The reason for this is that the EKC hypothesis is based on the relationship between environmental quality and increases in per capita income; thus, using only positive changes enables us to test the existence of the EKC hypothesis in the sampled countries. In addition to these regressors, consistent with the literature, we include other variables to control for their influence on the quality of the environment. The inclusion of the control variables is necessitated by the fact that the omission of many relevant variables from our model may cause misleading results. Other variables captured in the model are renewable energy consumption, energy prices, financial development, capital formation, imports, and exports.

We proxy renewable energy consumption as a percentage share of final energy consumption, and energy price with the Brent oil price index. Exports are represented by the exports of goods and services in the constant local

[1] The details are provided in Hsiao (2007).

[2] For an explanation, see Baltagi (2005).

currency, and imports are represented by the imports of goods and services in the constant local currency. Our proxy for financial development is domestic credit, which the financial sector provides as a percentage share of GDP, and capital formation is associated with gross fixed capital formation in constant local currency. The data sources used in this study are the 2021 World Development Indicators (WDI) databank (World Bank, 2021) and the US Energy Information Administration's (EIA) website.

The selection of control variables was guided by the existing relevant literature. All the variables are important as far as environmental quality is concerned. For instance, the literature documents that, among other measures, renewable energy use is an effective strategy for achieving clean energy. Energy from renewable sources reduces environmental issues, guarantees energy security, produces little secondary waste, and meets present and future social and economic needs (Gorus & Aslan, 2019; Wang, Sun, Guo, & Li, 2023). The inclusion of renewable energy in a country's energy mix is one of the most popular mechanisms for breaking the long-standing connection between fuel, CO_2 emissions, pollution, and economic growth (Ike et al., 2020). The inclusion of renewable energy consumption in the energy mix of every country is not only important but also necessary for attaining higher economic growth in every country. Driving economic growth is not the culprit in environmental degradation, but the type of energy used to achieve the growth. Therefore, reducing economic growth to reduce CO_2 emissions and protect the environment will do more harm than good to a country. Policymakers have thus recommended utilizing energies from renewable sources as substitutes for energies from conventional sources, since using the latter is associated with the emission of a large amount of CO_2, which is harmful to the environment.

The price of energy affects both its production and its use in oil-producing countries. The turning point in the EKC could differ if energy prices are omitted (Richmond & Kaufmann, 2006). More so, including energy prices in a model resolves the problem of endogeneity (Moutinho et al., 2020). Regarding financial development, the financial region affects a country's energy consumption (Tamazian & Rao, 2010). The financial sector mobilizes savings and distributes resources to creative endeavors, leading to opportunities to enhance local production, thereby causing environmental deterioration (Nazir et al., 2018). The more developed the financial sector is, the more it can provide individuals and firms with funds for various economic purposes. This increases the use of environmental resources and, as a result, affects the quality of the environment.

Trade is an essential component of EKC literature; thus, by including it, the result will potentially reveal that a country or countries have addressed their environmental problems when they have merely transferred them to other places (Karsch, 2019). Trade promotes economic activity, causing pollution (Mahmood et al., 2020). On the other hand, trade may reduce environmental pollution through the effects of composition and technique since it potentially boosts economic growth by pursuing a clean environment through strict environmental regulations and pollution-reducing innovations (Dinda, 2004). An increase in exports places pressure on natural resources and, by extension, puts the environment under immense pressure. This is because an increase in exports increases the production base of a country, which requires high demand and use of natural resources. Imports, on the other hand, embolden the importation of cleaner technologies and decreases CO_2 emissions (Runge, 1990). If, on the other hand, the imports do not promote the importation of cleaner technologies but favor the importation of environmentally unfriendly technologies, the result will be a decline in environmental quality. All else being equal, capital formation boosts the growth of economic activities and puts more pressure on environmental resources, thus causing deterioration of the environment.

3.2. Model Specification

In this study, we check the validity of the EKC proposition in oil-producing countries in Africa. In addition, we examine the impact of renewable energy consumption, energy prices, imports and exports, financial development, and capital formation on environmental quality, as well as the association between environmental quality and the regressors. To achieve these objectives, we employ the panel version of the Pesaran, Smith, and Shin (1996) and

Pesaran, Shin, and Smith (2001) ARDL models and the Dumitrescu and Hurlin (2012) Granger non-causality test. It is necessary to state that since the EKC hypothesis is propounded based on the relationship between increases in per capita income and environmental quality, we decompose the per capita economic growth series into two, i.e., the positive (increase) and negative (decrease) series and use only the increase series in our model. To do this successfully, we must generate positive changes in economic growth, following (Shin et al., 2014). Based on this framework, we decompose the per capita economic growth series as follows:

$$y_{i,t} = y_{i,0} + y^{+}_{i,t} + y^{-}_{i,t} \quad (1)$$

$$i = 1, 2, \ldots\ldots\ldots\ldots, N, \qquad i = 1, 2, \ldots\ldots\ldots\ldots, T.$$

In Equation 1, y_0, $y^{+}_{i,t}$ and $y^{-}_{i,t}$, respectively denote the initial values of economic growth, which are arbitrarily determined for country i at time t, partial increases in economic growth for country i at time t, and partial decreases in economic growth for country i at time t. Given Equation 1 and following Shin et al. (2014), we construct our panel nonlinear ARDL model as follows:

$$y_{i,t} = \rho^{+} y^{+}_{i,t} + \rho^{-} y^{-}_{i,t} + \varepsilon_{i,t} \qquad (2)$$

Where $y^{+}_{i,t}$ is a positive change in economic growth for ith country at time t, $y^{-}_{i,t}$ is a negative change in economic growth for ith country at time t, and $\varepsilon_{i,t}$ is the white noise error term, which is assumed to have no unit root, i.e., it has zero mean and constant variance $(\varepsilon_{i,t} \approx IID[0, \delta^2_{\varepsilon}])$. ρ^{+} is the slope of an increase in economic growth, while ρ^{-} is the slope of a decrease in economic growth. Equations 3 and 4 are the respective partial sums of increases and decreases in economic growth.

$$y^{+}_{i,t} = \sum_{v=1}^{V} \Delta y^{+}_{t,t} = \sum_{v=1}^{V} max(\Delta y_{i,t}, 0) \qquad (3)$$

and

$$y^{-}_{i,t} = \sum_{v=1}^{V} \Delta y^{-}_{i,t} = \sum_{v=1}^{V} min(\Delta y_{i,t}, 0) \qquad (4)$$

We only use positive changes in economic growth since the aim is to investigate the interaction between increases in economic growth and environmental quality. Equation 5 shows the panel ARDL model.

$$\Delta q_{i,t} = \lambda_{i,t} + \sum_{n=1}^{N} \varphi_u \Delta q_{i,t-u} + \sum_{n=0}^{N} \varphi_v \Delta y^{+}_{i,t-v} + \sum_{n=0}^{N} \varphi_w \Delta {y^{+}_{i,t-w}}^{2} + \sum_{n=0}^{N} \varphi_x \Delta k_{i,t-x} + \phi\Big(q_{i,t-1} - \Big[\delta_0 + \tau_1 y^{+}_{i,t-1} + \tau_2 {y^{+}_{i,t-1}}^{2} + \tau_3 k_{i,t-1}\Big]\Big) + \xi_{it} \qquad (5)$$

Where $q_{i,t}$, $y^{+}_{i,t}$, $y^{+\,2}_{i,t}$ and $k_{i,t}$ denote the quality of the environment proxied with per capita CO_2 emissions for the ith country at time t, economic growth is proxied with GDP per capita for the ith country at time t, and nonlinear economic growth for the ith country at time t and a set of control variables for the ith country at time t, respectively, are all expressed in log form.[3] The coefficients ϕ_u, ϕ_v, ϕ_w and ϕ_x represent short-run coefficients of a year lagged dependent variable, economic growth, squared economic growth and control variables, respectively. τ_i are the long-run coefficients of the regressors, while φ denotes adjustment speed to the long-run equilibrium. We estimate Equation 5 using the pooled mean group (PMG) estimator developed by Pesaran, Shin, and Smith (1999). Samarkand, Fidrmuc, and Ghosh (2015) identified the attributes of the PMG estimator as follows: The short-run coefficient, intercept, and adjustment speed to the long-run equilibrium, as well as the error variances produced, are heterogeneous across countries. The long-run parameters are homogeneous across countries.

The estimator is appropriate if there is a level association between the dependent and the repressors in the ARDL model (Eberhardt & Teal, 2011). Hsiao, Pesaran, and Tahmiscioglu (1999) noted that the PMG estimator combines both the pooling and averaging of variable parameters compared to its counterparts, in which the country-specific coefficients of regression are averaged. This enables it to produce the best estimates, especially in

[3] A regressor with a positive coefficient aggravates environmental quality, whereas a regressor with a negative coefficient promotes environmental quality.

cases where the N or T dimensions of the dataset are not large. Haider et al. (2020) opined that it allows the analysis of long-run homogeneity without making the assumption of identical short-run dynamics in each country, as opposed to other estimators, such as the Arellano and Bond (1991) GMM estimator, where only intercepts can vary across countries. This estimator does not depend on less plausible assumptions when making analyses of the long-run homogeneity of specific short-run identical dynamics (Frauke, 2011). The estimator analyzes data that are I(0) and I(1) or that combine variables that are I(0) and I(1) and produces estimates that are consistent, even when endogeneity is present, because they include lags of both outcome and independent variables (Pesaran et al., 1999). Equation 6 is the error correction model.

$$\Delta q_{i,t} = \lambda_{i,t} + \sum_{n=1}^{N} \varphi_u \Delta q_{i,t-u} + \sum_{n=0}^{N} \varphi_v \Delta y_{i,t-v}^{+} + \sum_{n=0}^{N} \varphi_w \Delta {y_{i,t-w}^{+}}^{2} + \sum_{n=0}^{N} \varphi_x \Delta k_{i,t-x} + \pi \xi_{t-1} \quad (6)$$

Where ξ_{t-1} denotes the error correction term, while π is the coefficient of the error correction term that shows the speed at which the variables return to their long-run equilibrium in the presence of a shock.

The causality between the quality of the environment and the regressors of Equation 4 is examined using the Dumitrescu and Hurlin (2012) Granger non-causality test. Equations 6 and 7 are the Granger non-causality test models.

$$j_{i,t} = \partial_i + \sum_{f=1}^{F} \lambda_i^{(f)} j_{i,t-f} + \sum_{f=1}^{F} \sigma_i^{(f)} h_{i,t-f} + \varepsilon_{i,t} \quad (7)$$

$$h_{i,t} = \partial_i + \sum_{f=1}^{F} \sigma_i^{(f)} h_{i,t-f} + \sum_{f=1}^{F} \lambda_i^{(f)} j_{i,t-f} + \varepsilon_{i,t} \quad (8)$$

Where $j_{i,t}$ and $h_{i,t}$ are two stationarity variables observed for N individuals in T periods, and ∂_i, $\sigma_i = (\sigma_1^{(1)}, \ldots, \sigma_i^{(F)})'$ and $\lambda_i = (\lambda_1^{(1)}, \ldots, \lambda_i^{(F)})'$ are the individual effects and are assumed to be fixed in time. We test the null hypothesis of no causal relationship for any of the cross-section units against the alternative hypothesis of the presence of at least one causality in the cross-section units. We state the null hypotheses as follows

for Equation 7:

$$H_0 = \sigma_i = 0, \text{ for } \forall_i = 1, 2, \ldots, \quad N$$

and

$$H_1 = \begin{Bmatrix} \sigma_i = 0 & for\ \forall_i = 1, 2, \ldots, & N_1 \\ \sigma_i \neq 0 & for\ \forall_i = 1, 2, \ldots, & N \end{Bmatrix}$$

And for Equation 8:

$$H_0 = \lambda_i = 0, \ \forall_i = 1, 2, \ldots, \quad N$$

and

$$H_1 = \begin{Bmatrix} \lambda_i = 0 & for\ \forall_i = 1, 2, \ldots, & N_1 \\ \lambda_i \neq 0 & for\ \forall_i = N_1 + 1, \ldots, & N \end{Bmatrix}$$

In carrying out the test, the Shwartz Bayesian Criterion (SBC) is used to select the optimal lag included. If we reject the null hypothesis, the alternative is accepted, and the conclusion is that there is causality in the cross-section units.

4. RESULTS AND ANALYSIS

Table 1 reports some essential attributes of the whole series. All series are consistent since the mean value of each falls between the respective least and greatest values of the series used. All the series, except squared economic growth, which has a standard deviation value of 44.3606, are less variable.

Table 1. Descriptive statistics.

Variable	Obs.	Mean	Std. dev.	Min.	Max.
$\ln q$	600	-0.41	1.63	-4.77	2.42
$\ln y$	600	4.85	4.16	-0.19	14.12
$\ln y^2$	600	40.80	44.36	0	200.76
$\ln r$	600	3.36	1.54	-2.83	4.61
$\ln p$	600	3.67	0.68	2.55	4.72
$\ln x$	600	26.76	2.39	20.04	31.79
$\ln m$	600	26.70	2.17	20.83	30.44
$\ln f$	600	25.92	2.68	15.47	31.27
$\ln d$	600	2.58	1.08	-0.80	4.74

Note: $\ln q$ = Natural log of environmental quality, $\ln y$ = Natural log of economic growth, $\ln y^2$ = Natural log of squared economic growth, $\ln r$ = Natural log of renewable energy consumption, $\ln p$ = Natural log of energy price, $\ln x$ = Natural log of exports, $\ln m$ = Natural log of imports, $\ln f$ = Natural log of capital formation, and $\ln d$ = Natural log of financial development.

We assess the stationarity of our series using the Breitung (2001); Haider et al. (2020); Im, Pesaran, and Shin (2003) and Maddala and Wu (1999) unit root tests. The results of all the tests are reported in Table 2. None of the series contains a unit root, either at level or first difference, since we do not accept the null hypothesis of all the tests except Hadri's. Note that the Hadri (2000) unit root test supports the null hypothesis that the panels contain a unit root, suggesting that for a series to be stationary, we must accept the null hypothesis. The results in Table 2 provide compelling evidence to accept the null hypothesis of the Hadri test for the series, implying that, just like the results of the other tests, all the series are stationary.

Table 2. Unit root test results.

Variable	IPS	LLC	Breitung	Hadri	ADF Fisher	Pesaran CD
$\ln q$	-1.66**p	-5.23***p	-12.31***q	-1.53q	188.66***q	-3.06***q
$\ln y$	-9.60***p	-4.46***p	-6.12***p	-3.51q	85.70***p	-2.08*p
$\ln y^2$	-9.71***p	-3.96***p	-5.45***p	-3.16q	77.01***p	-4.19***q
$\ln r$	-13.97***q	-10.32***q	-10.16***q	0.19q	170.48***q	-3.00***q
$\ln p$	-11.59***q	-1.32*p	-1.78**p	-1.55q	129.02***q	-2.61***q
$\ln x$	-12.33***q	-8.56***q	-12.56***q	-0.20q	126.02***q	-2.49***q
$\ln m$	-12.96***q	-11.81***q	-12.14***q	-0.75q	54.36*p	-2.66***q
$\ln f$	-11.01***q	-4.18***p	-9.06***q	-0.74q	110.13***q	-2.12***p
$\ln d$	-12.14***q	-9.73***q	-8.63***q	-2.35q	135.67***q	-2.84***q

Note: ***, ** and * denote statistical significance at 1%, 5% and 10%, while p and q denote stationarity at level and at first difference, respectively.

The short-run estimates reported in Table 3 reveal a negative statistically significant coefficient of linear economic growth and a positive statistically significant coefficient of nonlinear economic growth. This finding does not lend credence to the EKC hypothesis. In other words, the short-run association between economic growth and the quality of the environment is U-shaped, indicating the absence of the EKC proposition. The finding indicates that in the short run, these countries shift from environmentally friendly to environmentally unfriendly production processes, which is consistent with Pata and Kartal (2023) in the context of China, and Zambrano-Monserrate et al. (2018) in the case of Peru. Our findings further demonstrate that in the short run, if linear economic growth witnesses a 1% rise, the quality of the environment improves by 0.04%, while a 1% improvement in nonlinear economic growth is associated with a 0.005% deterioration of the environment.

Energy prices have a positive and statistically significant influence on the quality of the environment in the short run, suggesting that a rise in energy prices strongly reduces the quality of the environment in the short run. This finding is expected for oil-producing countries since an increase in energy prices is synonymous with an increase in revenue. An increase in the price of energy will potentially encourage them to produce and sell more energy. But if producing more energy is not carried out carefully, it will be to the detriment of the environment. The finding highlights the observation made by Malik et al. (2020), who demonstrated that prices of oil increase CO_2 emissions but run contrary to Ike et al. (2020), who reported an inverse relationship between energy prices and CO_2. A 1% rise in energy prices translates into a 0.08% fall in environmental quality in the short run.

Capital formation has a positive, but not statistically significant, effect on environmental quality. It indicates that the variable plays a negligible role in reducing environmental quality in the short run. This outcome does not confirm Zubair, Samad, and Dankumo (2020), who reported a negative and significant impact of capital formation on CO_2 emissions in Nigeria. Our evidence reveals that a rise in capital formation by 1% accounts for a 0.0362% decrease in environmental quality in the short run.

Table 3. Short- and long-run PARDL results.

Constant	$\ln y$	$\ln y^2$	$\ln r$	$\ln p$	$\ln x$	$\ln m$	$\ln f$	$\ln d$	ξ_{t-1}
Short run									
-2.43*** (0.49)	-0.04** (0.02)	0.005** (0.00)	-0.38 (0.41)	0.08** (0.03)	0.03 (0.08)	-0.03 (0.09)	0.03 (0.0865)	0.02 (0.04)	-0.42*** (0.09)
Long run									
-	0.02*** (0.00)	-0.003*** (0.00)	-0.58*** (0.07)	-0.02** (0.01)	0.11*** (0.03)	0.10*** (0.03)	0.09*** (0.02)	0.13*** (0.02)	-

Note: *** and ** denote significance at 1% and 5%, respectively. The standard error values are in parentheses.

The argument for the positive influence of capital formation on the quality of the environment is that capital formation in these countries promotes activities that put pressure on the environment and, as a result, reduce environmental quality. Likewise, the short-run impact of financial development on the quality of the environment is positive but statistically insignificant, which means that financial development adds but negligibly to environmental deterioration in the short run. This finding is justified given the fact that a more developed financial system provides the public with easier access to finance for economic activities that worsen the quality of the environment. The financial sector mobilizes savings and distributes resources to creative endeavors, thus providing an opportunity to enhance local production that leads to the deterioration of the environment (Nazir et al., 2018). Our findings demonstrate that a rise in financial development of 1% degrades the environment by 0.02% in the short run.

The effect of renewable energy consumption on the quality of the environment is negative but statistically insignificant in the short run. This means that renewable energy consumption improves the quality of the environment in the short run, but only minimally. We expect this renewable energy consumption to influence environmental quality since it provides cleaner energy. This suggests that the inclusion of renewable energy in these countries' energy mix in an attempt to protect the environment from being destroyed yields some results in the short run and validates Ike et al. (2020); however, it is inconsistent with Pata and Caglar (2021), who documented that renewable energy consumption has no effect on the quality of the environment. The short-run renewable energy consumption coefficient is -0.38 and suggests that the quality of the environment improves by 0.38% with a 1% increase in renewable energy consumption. Likewise, the impacts of exports and imports on environmental quality are negative but not significant, indicating that exports and imports have an inconsequential effect on enhancing environmental quality in the short run. Though the short-run influence of both exports and imports on improving the quality of the environment is not statistically significant, a plausible explanation for this is that, in the short run, importation and exportation somewhat obey environmental rules. The coefficients for exports and imports in the short run are -0.04 and -0.03, respectively, indicating that an improvement in exports and imports of 1% respectively improves the quality of the environment by 0.04% and 0.03%. The short-run relationship between exports and the quality of the environment agrees with Mahmood et al. (2020), but the short-run association between imports and environmental quality does not. Evidence of a long-run association between the quality of the environment and all our predictor variables was observed. The parameter of the model's error correction term is -0.42, which indicates the possibility of convergence to the long-run equilibrium of the variables in the model whenever there is a short-run shock. Precisely, 42.0% of the short-run deviation of these variables from their long-run equilibrium is corrected in the current period until the variables are in their long-run equilibrium. That is, it takes the variables approximately 1.4 years to converge to their long-run equilibrium whenever there is a short-run deviation from equilibrium, and in the presence of natural shocks to environmental degradation, deviation from the long-run equilibrium is recovered within a short period of time.

In the long run, the effect of linear economic growth on the quality of the environment is positive and statistically significant, while the influence of nonlinear economic growth on environmental quality is negative and statistically significant. This finding supports the EKC proposition, which postulates that at the initial stage of a country's growth, the quality of the environment deteriorates but eventually improves with an increase in income. This suggests that at the initial stage of attaining higher economic growth in the long run, countries have greater potential for increasing the quality of their environment; however, as they continue to grow, industrial competitiveness and the use of advanced technologies bring about greater improvement in the quality of the environment, and if the trend continues, the destructive effect on the environment will vanish eventually. In other words, economic growth is the ultimate means of sustaining the environment in the long run. Our finding is in tandem with Islam et al. (2013), Rana and Sharma (2019), Nazir et al. (2018), Malik et al. (2020), Tiba and Frikha (2019), Gorus and Aslan (2019), Kisswani et al. (2019), Mahmood et al. (2020), Bulut (2021), Ongan et al. (2021), and Vanli (2023), but does not support (Kisswani et al., 2019). We found that, in the long run, a 1% increase in linear economic growth reduces environmental quality by 0.02%, while a 1% increase in nonlinear economic growth promotes environmental quality by 0.003%.

The coefficient of renewable energy consumption in the long run is -0.58 and is statistically significant, which means that renewable energy consumption is consistent with environmental quality in the long run. This finding is expected because renewable energies provide clean energy, as confirmed by Ike et al. (2020). However, this finding contradicts that observed by Pata and Kartal (2023), who reported that renewable energy consumption does not enhance environmental quality significantly in the long run. Prices of energy have negative and statistically significant effects on the quality of the environment in the long run, suggesting that, in the long run, energy prices are necessary for improving environmental quality. An increase in the price of energy will provide these countries with more revenue and, therefore, more capacity to protect the environment from being destroyed. Our finding corroborates Ike et al. (2020). We also found that a 1% rise in oil prices improves the quality of the environment by 0.02% in the long run.

The long-run coefficients of exports, imports, capital formation, and financial development are positive and statistically significant. The respective parameters of these variables are 0.11, 0.10, 0.09, and 0.13, meaning that a 1% improvement in exports, imports, capital formation, and financial development will reduce the quality of the environment by 0.11%, 0.10%, 0.09%, and 0.13%, respectively. The implications are that, in the long run, exports, imports, capital formation, and financial development threaten the environmental quality of oil-exporting countries in Africa. The impact of exports on the quality of the environment in these countries could be a result of not using cleaner technologies in producing goods for export. It could also result from not obeying environmental rules in the exportation of goods. This finding contradicts Mahmood et al. (2020).

Regarding the effect of imports, we hypothesize that, in addition to ignoring environmental rules, importation in these countries increases fossil fuel energy utilization, thereby worsening the quality of the environment. Another plausible explanation for this is that these countries favor the importation of inferior and environmentally unfriendly technologies. The long-term association between imports and the quality of the environment confirms Mahmood et al. (2020). Capital formation may increase the use of energy from conventional sources, thus contributing to the deterioration of the environment in the long run. Regarding financial development, as mentioned earlier, the development of the financial market does not only provide easy access to funds for firms and individuals but also provides them with access to more funds, which increases the production and utilization of goods and services, thus exerting more pressure on the environment in the long run.

Table 4. Granger causality test.

Causality	z-bar	z-bar tilde	Causality	z-bar	z-bar tilde
From $\ln y$ to $\ln q$	-0.68	-0.82	From $\ln q$ to $\ln y$	3.62	2.91
From $\ln y^2$ to $\ln q$	0.80	0.46	From $\ln q$ to $\ln y^2$	3.97***	3.21***
Form $\ln r$ to $\ln q$	4.81***	3.94***	From $\ln q$ to $\ln r$	7.26***	6.06***
From $\ln p$ to $\ln q$	4.71***	3.85***	From $\ln q$ to $\ln p$	5.30***	4.36***
From $\ln x$ to $\ln q$	4.88***	4.00***	From $\ln q$ to $\ln x$	2.89***	2.27**
From $\ln m$ to $\ln q$	7.66***	6.41***	From $\ln q$ to $\ln m$	9.27***	7.80
From $\ln f$ to $\ln q$	0.22	-0.04	From $\ln q$ to $\ln f$	6.39***	5.30***
From $\ln d$ to $\ln q$	5.89***	4.87***	From $\ln q$ to $\ln d$	7.99***	6.70***

The Dumitrescu and Hurlin (2012) Granger non-causality test aims to assess the causal relationship between environmental quality and the regressors. Table 4 presents the non-causality test results. A unidirectional causality was detected that runs from environmental quality to growth and nonlinear growth. Both the z-bar and the z-bar tilde values of the test for the null hypothesis that environmental quality does Granger-cause economic and nonlinear economic growth are rejected at 1%, whereas the z-bar and the z-bar tilde values of the null hypothesis that economic growth and squared economic growth do not Granger-cause the quality of the environment are not rejected. This indicates that while the quality of the environment predicts economic growth and nonlinear economic growth, economic growth and nonlinear economic growth do not predict the quality of the environment. A feedback effect was observed between environmental quality and renewable energy utilization, which suggests that renewable energy use can remedy environmental problems and that environmental quality affects renewable energy consumption. Likewise, a bidirectional causality was observed between the quality of the environment and exports, imports, and financial development. The causal association between the quality of the environment and exports suggests that exports predict the quality of the environment, and likewise environmental quality predicts exports. Similarly, the causal association between environmental quality and imports indicates that the two variables predict each other. The feedback effect between financial development and the quality of the environment means that the development of the financial sectors in African oil-producing countries predicts the quality of the environment, and likewise, the quality of the environment predicts financial development. A unidirectional causality runs from environmental quality to capital formation, implying that while the quality of the environment forecasts capital formation, the reverse is not the case.

5. CONCLUSION AND POLICY IMPLICATIONS

This study tested the EKC hypothesis and examined the impact of renewable energy consumption, energy price, exports, imports, financial development, and capital formation on environmental quality in oil-producing countries in Africa using the panel ARDL model. It also assessed the causal association between environmental quality and economic growth, renewable energy consumption, energy prices, exports and imports, capital formation, and financial development. The frequency of the data used is yearly and spans from 1991 to 2019. The pooled mean group (PMG) estimator is used to estimate the PARDL model. The estimates revealed that, in the short run, the association between economic growth and environmental quality is U-shaped, implying that the EKC hypothesis is not valid in the short run. That is, higher growth in the economies of oil-producing countries in Africa is not a potential remedy for environmental degradation in those countries in the short run. However, in the long run it was found that the relationship between higher growth in the economies of those countries and environmental quality is inverted U-shaped, lending credence to the EKC hypothesis. This implies that attaining higher economic growth is the ultimate remedy to the environmental degradation of oil-producing countries in Africa in the long run. Furthermore, in the short run, it was observed that energy price is a strong factor that reduces environmental quality, while financial development and capital formation deteriorate environmental quality. However, the consumption of renewables, exports, and imports has little effect on improving the environmental quality of oil-producing countries in Africa.

In the long run, exports, imports, financial development, and capital formation were confirmed as key drivers of environmental degradation. However, energy prices and renewable energy consumption were found to significantly improve the quality of the environment in the long run. The Granger causality test revealed unidirectional causality from environmental quality to economic growth, squared economic growth, and capital formation, and confirmed evidence of bidirectional causality between environmental quality and energy price, consumption of renewable energy, exports, imports, and financial development.

These findings have some policy implications. Policies targeted at improving the quality of the environment in these countries will be beneficial in the short run since the relationship between economic growth and environmental quality is U-shaped. Hence, rather than doing nothing, the government should implement measures that protect the environment from being destroyed in the short run. But in the long run, environmental policies will be highly beneficial in these countries only when economic growth is at a level where the quality of the environment is declining. At the growth level when the quality of the environment improves, i.e., after the EKC turning point, these policies may be redundant. Furthermore, as the inclusion of renewable energy consumption in the energy mix of African oil production countries yielded positive results, environmental policies should emphasize greater inclusion of renewable energy consumption in these countries.

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Appendix (List of countries)

Algeria, Congo, Ghana, Niger, Angola, Cote d'Ivoire, Libya, Nigeria, Cameroon, Egypt, Malawi, North Sudan, Chad, Equatorial Guinea, Mauritania, South Africa, Democratic Republic of the Congo, Gabon, Morocco, and Tunisia.