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RESEARCH ARTICLE

The environmental aspects of conventional and clean energy policy in sub-Saharan Africa: is N-shaped hypothesis valid?

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Abstract

In the energy-environment literature, a handful of the advanced economies, mostly the European Union countries, have met some of the national environmental sustainability targets. Consequently, most of these countries are renewing their policies for 2040, while the African bloc largely seems to have a longer path to emerge from the woods. Giving this insight, we are compelled to draw inferences from the role of major energy sources (conventional and renewable) in the sub-Saharan Africa's drive for environmental sustainability target. To achieve this objective, we examine the validity of an N-shaped hypothesis for sub-Saharan region which has received less documentation in the extant literature. Thus, this study employed the pooled mean group autoregressive distributed lag (PMG-ARDL) and Dumitrescu and Hurlin panel causality approaches as estimation techniques. Our empirical results show that conventional and renewable energy aspects respectively worsen and improve environmental quality in both short and long run. Importantly, the study establishes the validity of the N-shaped hypothesis in the two periods (short and long run) as reported by the study regression with 17.830% for GDP growth, −2.241 % for quadratic form of GDP, and 0.094% for cubic form of GDP growth, respectively, in the long run. Moreso, renewable energy shows a magnitude of −1.306% and −0.157% for short- and long-run period, respectively, on carbon dioxide emission. The implication is that environmental quality in the sub-Saharan region is potentially characterized in cycles of worse (decreased quality), improvement (better quality), and again worse (deceased quality) resulting from the significant change in the region's economic prosperity. In addition to the ARDL approach, the causality analysis further reiterates that there is significant causality from the energy forms and economic expansion to carbon emission at least in one direction. While examining the validity of N-shaped hypothesis for the first time for Africa, the study offers policy perspective to the governments and environmental stakeholders in the panel countries, especially to re-engineer the region's economic dynamics if the region must meet the anticipated Sustainable Development Goals 2030.

Keywords Environmental sustainability · Renewables · Growth aspects · N-shaped hypothesis · Sub-Saharan Africa

Introduction

The transition to a low-carbon economy is an essential component of the sustainable development (UN SDG) agenda. Increasing the share of renewable energy in the energy mix (SDG Target 7) and doubling the rate of improvement in energy efficiency (SDG Targets 11 and 12) are among many policy options currently considered to have the potential to

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facilitate the transition. Following the UN-SDG-13 agenda to decrease ecological degradation, this analysis addresses this important issue by analyzing the impact of energy consumption and renewable energy consumption in the conventional N-shaped EKC hypothesis for the sub-Saharan African countries. Environmental issues, on the other hand, have become topical conversation, and it is gaining attention now among stakeholders and intergovernmental organization on how to sustain environmental quality and stable environmental economic growth (Destek and Sarkodie 2019). Any increase in energy consumption emanating from CO_2 emission is related source in ensuring that economic growth is linked with higher levels of CO_2 emission which is detrimental to human health and environment. However, carbon dioxide intensity in developing countries is hindrance to their struggle in the direction of economic growth, by this means endorsing the need for industrial economies to intensify finance programs to alleviate global warming enormously caused by their undertakings (Alola and Kirikkaleli 2019).

Notwithstanding, a great step was taken by Kyoto (1997) protocols to drastically minimize greenhouse gasses caused by industrialized economies. Ever since the expansion of world economy is dependent on carbon concentrated energy, minimizing energy usage or scarcity of energy supply has thoughtful repercussion for income (Gyamfi et al. 2021a, b, c). Moreover, environmental sustainability also directs the economy to the implementation of healthier output which is widely confirmed by the EKC phenomenon. While most analysis has concentrated on validating the null assumption, in this regard, it cannot show and safeguard progress as well as prosperity that are likely to safeguard environmental security and environments. The use of the N-shaped Kuznets curve therefore enables the relationship regarding environmental efficiency and income to be invalidated or verified (Aljadani et al. 2021). The link between CO_2 emission and income definitely has gain unique thoughtfulness as defined by environmental N-shaped curve hypothesis. Per this hypothesis, the association between income and the levels of pollution takes the shape of an inverted u-curve; at the early stage growth, the level of pollution increases as the country develops, but after reaching a particular stage of expansion, the level of pollution turns to upsurge. Relatively, it is assumed that the quality of environment of an economy deteriorates before it advances. Comparatively, pollution increases with economic growth and falls after accomplishing a certain verge value. The environmental Kuznets curve hypothesis describes this trend of environmental deterioration, stating that environmental quality worsens at first when income lowers but improves as income rises (Zhang 2021: Gyamfi et al. 2021a).

However, increased reliance on fossil fuel, as well as energy shortages and troubling environmental degradation, have increasingly compelled many nations around the world (including our investigation area, i.e., the sub-Saharan Africa) to seek for alternative energy sources. Renewable energy have long been accepted as a viable alternative to fossil fuel in the foreseeable future. With the worldwide energy usage dimensions, it is so far identified as the best alternative. It is worth noting that, despite the fact that the renewable energy sector has seen incredible rise, especially in solar-wind energy, the percentage of renewable energy usage alone has overstimulated the current history. This may be due to the high demand for energy usage and the widespread usage of conventional biomass for heating (summing up almost partial of all renewable energy utilization). Conversely, renewable share of global electricity generation is projected to rise from 18 in 2007 to 23% in 2035, with geothermal energy and clean power contributing 50% and 26% collectively (Apergis and Payne 2012). While state policies, continue declines in renewable energy technologist cost, and increasing energy needs can all be blamed for the significant growth forecast and regional expansions of renewable energy. There has been a decent reaction from the public to embrace renewable energy.

Since 2016, African countries such as Nigeria and Angola are reportedly among the world's leading crude oil-producing economies. As a result, Nigeria causes 300 oil spills every year, increasing ecological deterioration (U.S Energy Information Administration 213). The African continent has only deaths of approximately 770 thousand a year, resulting in considerable harm to human safety. Of these pollutants combined, CO_2 emissions contribute to over 40,000 deaths. Nonetheless, 600,000 people have been affected by airborne toxins caused by pollution in sub-Saharan Africa. The harm incurred by CO_2 emissions has lost many lives in recent years. With regard to efficiency for growth and development, we must bear in mind that the degree of successful results of one country has a fundamental influence on all areas of sustainable development in this particular region. Furthermore, the planet has an era of sustainable development objectives (SDGs), to be fulfilled by the nations by 2030. In this context, it seems necessary to reflect on the actual energy of a nation, along with other economic proposals, to analyze its capabilities to attain the SDG targets. This study therefore aims to analyze environmental mitigation techniques in the countries of Saharan Africa, apart from the empirical aspect, by focusing on healthy manufacturing activities. Extensive study revealed a wide analysis on the impact of clean energy measures on developing economies, with particular focus on sub-Saharan African regions. The progress achieved in the regulation of carbon emissions as a consequence of industrialization and environmental emissions through sustainable revenues, energy use, and renewable energy use is objectively discussed in our study. We assess how revenue diverges directly and indirectly to ecological destruction. This study then provides a three-fold contribution in the current energy literature. We study the relationship among the economic growth and carbon emission, by incorporating central factors for sub-

Saharan African countries such as energy consumption and renewable energy consumption in the carbon-income framework. The inverted U-shaped is also discussed in the sense of the EKC theory that highlights the relationship between economic development and CO_2 emission. This study further contributes to the existing literature by elucidating the EKC argument by considering a possibility for N-shaped relationship between economic growth and environmental degradation in sub-Saharan Africa which have received less documentation in the extant literature. This is a gap in the existing EKC literature that this study seeks to fill by using PMG-ARDL regression to detect EKC in sub-Saharan Africa. Finally, the knowledge on the N-shaped EKC is not well known, and academics are still conducting study on the theme; hence, this present study will contribute to the existing body of knowledge by this extension for requisite policy formulations for environmental sustainability target in the region and other developing and emerging blocs.

The remaining part of the paper is structured in five sections. The "Literature review" section presents the review of related literature. The "Data and methodology" section and the "Empirical results and discussion" section provide the methodology and empirical result, respectively, while the "Conclusion and policy implications" section provides conclusion, recommendation, and implication for policy direction accordingly.

Literature review

The first section of the literature delves deeply into theoretical framework of the studies, while the next part looks at the empirical review of the study.

Theoretical framework

Economic growth and environmental sustainability are best analyzed using the environmental Kuznets curve (EKC) theory, which takes into account the scale, techniques, and composition of social operations. The scale effect is defined by pre-industrial fundamental shifts in the economy, in which restricted use of natural and compostable materials enables ecological emissions to be reduced. With the growth of the country's GDP, this results in intensive usage of agriculture as well as other environmental assets, such as forests, that accelerates the number of restoration (Gyamfi et al. 2021a). This results in the economy entering a transitional period characterized by increased industrialization as well as actions that degrade ecological sustainability. This phase of the economy's development is bolstered by increased progress and production at the expense of ecological deterioration. This also implies that as income levels increase, the economy's framework moves away from just a resource-intensive economy toward a knowledge-based economy. This step is pointed to as the composition effect, and it is marked by strict regulatory policies aimed at reducing ecological emissions via the production of healthier sectors. Established that this stage of economic growth requires improved resource allocation and effective resource use. Additionally, developing economies with rising incomes devote more resources to research and development in order to substitute outdated technology with new inventions. This phase is related to as the technical impact and is responsible for further improving the efficiency of the landscape. The cumulative impact of all of the aforementioned actions results in an inverted U-shaped association involving economic growth as well as ecological sustainability which is referred to as the environmental Kuznets (EKC) theory.

Numerous investigations have explained the connection regarding economic growth and ecological emissions. This assertion has been validated by investigating the EKC theory reliability. According to the EKC, there is a non-linear connection regarding economic advancement and ecological emissions. Additionally, this means that during the early period of growth, both economic growth and ecological emissions accelerate concurrently. This demonstrates that growth happens at the expense of ecological deterioration during the economy's beginning phases. Nevertheless, once a threshold is reached, ecological emissions decrease as economic growth accelerates. This is the level at which the economy has matured. This condition has been clarified previously by forecasting an inverted U-shaped association regarding economic growth and ecological emissions which is supported by the EKC hypothesis credibility (Grossman and Krueger 1991; Sinha et al. 2017; Gyamfi et al. 2021b). Additionally, some analyses have found an N-shaped association regarding ecological degradation and economic growth in contrast to the inverted U-shaped association. This means that during the early stages of growth, economic progress increases the amount of ecological emissions till the first pivotal moment and then decreases until the second pivotal moment. However, once the second transition point is reached, ecological degradation resumes its upward trend. Ecological adjustments occur in certain economic environments, since an improvement in income has a strong effect on ecological emissions. This also implies that if the state's renewable energy initiatives are not implemented and enforced during the second turning point for implementation of energy legislation, climate emissions will resume its upward trend. This final phase necessitates technological advancement in order to produce more effective goods that contribute to ecological emission mitigation (Sinha and Shahbaz 2018; Balsalobre and Alvarez 2016).

It is critical to note that the N-shaped association regarding environmental degradation and economic growth has indeed been clarified by taking into account the size, structure, and technological impact. Torras and Boyce (1998) proposed in their analysis that the scale effect occurs when income activity accelerates during the early phases of economic progress, thus deteriorating the climate. Hettige et al. (2000) clarified in their analysis that economic growth results in systemic changes as a result of the introduction of heavy industry, further deteriorating ecological sustainability. At this level, the economy transitions from heavy to light industry. Simultaneously, the processed goods are ecologically sustainable, thus enhancing the ecological performance as economic development increases. Thus, the mitigation of ecological emissions caused by light industry has an impact on the economy's process of structure. Álvarez-Herránz et al. (2017) added that technical advancements allow the adoption of cleaner technologies that are both more effective and less polluting. This advancement in the technological side of creation at a later point demonstrates the technical influence of the N-shaped EKC.

Empirical review

In the extant literature, studies have put forward several dimensions and factors that are directly or indirectly associated with environmental quality. The current sub-section x-rays the related studies in the context of the current case.

Renewable, non-renewable energy consumption and carbon dioxide emissions

Many studies have been conducted into the connection between GDP and energy (e.g., Nathaniel 2021; Nathaniel and Adeleye 2021; Ozturk 2010). Similarly, Apergis and Payne (2009) argue that there is causality which is bidirectional between energy usage and CO_2 utilizing data from Central American countries from 1971 to 2004. Seemingly, Apergis and Payne (2010a, b) found a bidirectional relationship between renewable energy and CO_2 emissions. Ito (2017) indicated that renewable energy consumption contributes to reduction of CO_2 emissions. Document that renewable energy consumption increase CO_2 emission. Furthermore, Apergis and Payne (2010a, b) found a bidirectional relationship between non-renewable energy and carbon dioxide emissions using Granger causality model via error correction model. Ito (2017) indicated that non-renewable energy consumption contributes to CO_2 emissions in the long run and short run. Study indicated that non-renewable energy consumption increase CO_2 emissions. Bhat (2018) altered that non-renewable energy consumption increase CO_2 and renewable is found to be positively impact CO_2. From view point of Schneider (2006), shifting from non-renewable energy to renewable energy source is an effective way to minimizing pollution utilizing common correlation effects model.

Renewable, non-renewable energy consumption and economic growth

Apergis and Payne (2010a) study shows that energy consumption significantly correlated with economic growth employing panel data for eleven commonwealth countries from 1992 to 2004. Apergis and Payne (2012) opined that there is bidirectional causality between renewable energy consumption and economic growth using data from 1984 to 2007. The study used data from 19 developing and developed countries. Apergis and Payne (2010b) show that there is bidirectional relationship between renewable energy usage and economic growth using data from thirteen Eurosia countries from 1992 to 2007. Alternatively, Apergis and Payne (2012) found a poor unidirectional relationship between nuclear energy and economic growth. Apergis and Payne (2010a, b) found a bidirectional relationship between renewable energy and economic growth. Sadorsky (2009) uses FMOLS in his study and found that GPD impact renewable energy consumption by three pint 5% in eighteen developing countries. Concurrently, employed OLS to opine that renewable energy usage positively impact China's economic growth. Also, Ito (2017) found that there is positive relationship between renewable energy and economic growth for developing countries.

Similarly, found a feedback relationship between renewable energy consumption and economic growth. Similarly, Apergis and Payne (2010a) discovered that there is bidirectional causality between non-renewable energy consumption and economic growth. Apergis and Payne (2010a, b) found a bidirectional relationship between non-renewable energy and economic expansion. Same authors Apergis and Payne (2010a, b) found a feedback relationship between non-renewable energy consumption and economic growth. Ito (2017) found that there is negative relationship between non-renewable energy and economic growth for developing countries. Bhat (2018) iterated that renewable energy consumption and economic growth is found to be positive but insignificant statistically.

Economic growth and carbon dioxide emissions

For many years, the link between economic growth and CO_2 emissions has been the subject of heated debate. Until 1970, there was a wide spread misconception that oil, raw materials, and consumption of natural resources grew at nearly the similar pace. Many extant studies support or refute the above assertions. Dinda (2004) put it another way that environmental pollution rises faster than income in the early stage of growth and then falls behind economic growth as income rises. Seemingly, Saint Akadırı et al. (2021) pointed out in his study towards unveiling additional economic freedom dimension within the facet of EKC indicating that in the short-run term, the effect of blocs energy mix such as natural gas, oil, and coal on the quality of environment is unfavorable; natural gas has the prospective to reduced carbon emissions solely in South Africa. On the other hand, Zhang (2021) utilized quantile regression as an inference approach and identified that instead of conventional U-shaped hypothesis, there is N-shaped relationship between carbon dioxide and economic growth in the long run. As indicated in Table 1, there are several other studies that have attempted to examine the validity of EKC and N-shaped hypothesis especially for a panel of handful countries.

The route of the outlined existing literature demonstrates a gap in the existing documentation for the desire to adequately investigate the relationship regarding income and CO_2 emission by obtaining the N-shaped EKC. The factors examined in this analysis are relevant and valuable in light of the literature's unclear findings in the energy-environment issue. However, Shahbaz et al. (2019) focused on the N-shape for countries in the Middle East and North Africa, Halliru et al. (2020) on six West African countries, and Gyamfi et al. (2021a) on the E7 economics. As a result, these recent analyses vary in their country selection by examining the N-shape for countries in sub-Saharan Africa.

Data and methodology

To achieve the objective of this study, a panel data from selected sub-Saharan African economies from the period of 1990–2015 was utilized (list is found in Appendix). The samples are chosen based on data availability. Further motivation for the selection of SSA stems from the region economic architecture and energy mix. Also, the bloc environmental emission reflects environmental deprivation caused by real gross domestic products (GDPC), renewable energy consumption (REC), and energy consumption from fossil fuel sources (EC). All data for variables are collected from the World Bank's World Development Indicators (WDI 2020). Table 2 gives a summary of the description of the variables:

While a good number of studies have jointly observed the nexus of non-renewable and renewable energy with carbon dioxide emissions (Inglesi-Lotz and Dogan 2018; Khoshnevis Yazdi and Shakouri 2017; Nguyen and Kakinaka 2019), the current studies have applied the concept for selected sub-Saharan African (SSA) countries which have received less attention by disaggregating energy consumption into energy consumption from fossil fuel sources and renewable energy after the previous literature already highlights. The choice of study variables also draws strength from the United Nations Sustainable Development Goals (UN_SDGs-7, 8, 11, 12, and 13) that highlights need for access to clean and affordable energy consumption, responsible energy consumption, sustainable economic, and climate change action. Additionally, our model uniquely incorporated cubic form for economic growth to extend the conventional EKC phenomenon to N-shaped trade-off between economic growth trajectory and environment status

Table 1 Summary of empirical literature concerning EKC relationship utilizing multi-country approach

Author(s)	Countries	Sample periods	Model	Energy data	EKC
Dinda et al. (2000)	68 countries	1960–1990	Quadratic	T/F	Yes
Gangadharan and Valenzuela (2001)	51 countries	Different periods	Cubic	T/F	No
Stern and common (2001)	73 countries	1960–1990	Quadratic	T/F	Yes
	24 countries	1960–1997	Cubic	T/f	Yes
Apergis and Payne (2009)	6 countries	1997–2004	Quadratic	T/f	Yes
	94 countries	1981–2000	Non-linear	T/f	Yes
Lee et al. (2010)	97 countries	1980 2001	Cubic	T/f	Mixed
Castiglione et al. (2012)	28 countries	1996–2008	Non linear	T/f	Yes
Ben Jebli et al. (2013)	25 OECD countries	1980–2009	Quadratic	RE	Yes
Bilgili et al. (2016)	17 OECD countries	1977–2010	Quadratic	RE	Yes
Bidi et al. (2020)	Europe and Central Asia, South Asia, the Middle East and North Africa, and sub-Saharan Africa	2000–2018	Quadratic	T/f	Mixed
Gyamfi et al. (2020a)	E7 economics	1990–2016	Non-linear	T/f	Mixed
Gyamfi et al. (2020b)	G7 economics	1990–2016	Non-linear	T/f	Mixed
Gyamfi et al. (2021a)	E7 economics	1990-2016	Cubic	T/f	Mixed
Asiedu et al. (2021a)	EU	1990–2016	Non-linear	T/f	Mixed
Asiedu et al. (2021b)	Chanda, Belgium, and USA	1990–2016	Non-linear	T/f	Mixed

Note: T/F indicates total/fossil energy consumption; RE refers to renewable energy consumption

Table 2 Variable description

Indicator	Symbol	Sources
Dependent variable	CO_2	World Development Indicator
Carbon dioxide emissions (Kt)		
Explanatory variable	GDPC	World Development Indicator
Real gross domestic product (US$ constant 20100)		
Conventional energy use (kg of oil equivalent)	EC	World Development Indicator
Renewable energy consumption (% of final energy consumption)	REC	World Development Indicator

Note: CO_2 emission is dependent variable, while explanatory variables, a priori sign, are expected to be positive for all covariates with exception to renewable energy consumption to be negative; however, it could be ambiguous

The equation provided below illustrates the model object of our investigation, which is defined first in a functional manner of:

$$CO_2 = f\,(GDPC, EC, REC) \quad (1)$$

The continuous stochastic form of the connection regarding carbon dioxide emissions, real gross domestic product, energy consumption from fossil fuel sources, as well as renewable energy consumption is shown as:

$$CO_{2i,t} = \beta_0 + \beta_1\, GDPC_{i,t,} + \beta_2\, EC_{i,t,} + \beta_3\, REC_{i,t,} + \varepsilon_{i,t} \quad (2)$$

Our analysis interpreted 1990 through 2016 as the time span being utilized in the analysis, and *i* and *t* indicate the cross-sectional and time units for this studies where "ε" is denoted as the error term. From there, square and cubic form was added to the real gross domestic product to access if the objective of obtaining the invented U-shaped and N-shaped for the studies can be achieved. The equation below illustrates the model:

$$CO_{2i,t} = \beta_0 + \beta_1\, GDPC_{i,t,} + \beta_2\, GDPC^2{}_{i,t,} + \beta_3\, GDPC^3{}_{i,t,} + \beta_4\, EC_{i,t,} + \beta_5\, REC_{i,t,} + \varepsilon_{i,t} \quad (3)$$

To ensure a more accurate result, all the parameters are in their logarithmic (log) form using the logarithm of each parameters, and the formula is as follows:

$$LCO_{2i,t} = \beta_0 + \beta_1\, LGDPC_{i,t,} + \beta_2\, LGDPC^2{}_{i,t,} + \beta_3\, LGDPC^3{}_{i,t,} + \beta_4\, LEC_{i,t,} + \beta_5\, LREC_{i,t,} + \varepsilon_{i,t} \quad (4)$$

where CO_2, GDPC, $GDPC^2$, $GDPC^3$, EC, and REC are denoted as CO_2 emissions, real gross domestic product, square of real domestic product, cubic of real domestic product, energy consumption, and renewable energy consumption, respectively.

However, the environmental Kuznets curve can develop numerous shapes because of the vector of real GDP on selected independent parameters according to Balsalobre and Alvarez 2016These shapes are in the form of:

➢If $\beta_1 = \beta_2 = \beta_3 = 0$, then there is not any relationship regarding ecological quality and economic development.

➢If $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$, then a rise in real GDPC will increase environmental quality.

➢If $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$, then a fall in real GDPC will decrease environmental quality.

➢If $\beta_1 < 0$ and $\beta_2 > 0$ and $\beta_3 = 0$, then presence of U-shaped curve will be obtained regarding ecological quality and economic development.

➢If $\beta_1 > 0$ and $\beta_2 < 0$ and $\beta_3 = 0$, then the inverted U-shaped EKC will be obtained.

➢If $\beta_1 > 0$ and $\beta_2 < 0$ and $\beta_3 > 0$, we will then have N-shaped association regarding ecological quality and economic development.

➢If $\beta_1 < 0$ and $\beta_2 > 0$ and $\beta_3 < 0$, we will then have an inverted N-shaped association regarding ecological quality and economic development.

According to this analogy, we look to see whether GDP and ecological quality shift in response to an expanding economy. Since the energy consumption and renewable energy consumption are both extremely unpredictable, the N-shaped EKC would be subject to drastic variations.

Moreover, the authors utilized the conventional unit root techniques of ADF and Im-Pesaran-Shin unit root techniques for identifying the stationarity of the variables. The Johansen multivariate cointegration analysis and Kao residual cointegration techniques are used to access the long-run cointegration among the variables.

However, to access the long-run equilibrium among the variables, the PMG-ARDL technique was utilized. A standardized ARDL approximation framework is unable to test for bias. It is unable because of the individual effect within the panel data model which is mostly bias. Based on this, a mixture of PMG technique by Pesaran et al. (1999) and ARDL model offers solution to the challenge conflicting to the unsuitable dynamic panel generalized method of moments (GMM) technique (Bekun et al. 2019). The ARDL cointegration approximation outperforms conventional panel data templates. It is worthy of adjusting for endogeneity in econometric interpretations while also accommodating both short- and long-run constraints. Additionally, the ARDL cointegration evaluation provides for use of the factors in a varying sequence of selection, for example, I(0) and/or I(1), rather than I(0) and/or I(1) (2). Pesaran et al. (1999) assert that the pool mean group (PMG) approximation is reliable, robust, and resistant to lag orders as well as exceptions.

However, conflicting to the present panel data techniques available in Destek and Sarkodie (2019) and Sarkodie and Strezov (2019), this analysis follows the PMG-ARDL technique applied in Bekun et al. (2019) and Gyamfi et al. (2020b), stated as:

$$\Delta \ln y_{i,t} = \phi_i ECT_{i,t} + \sum_{j=0}^{p-1} \ln X_{i,t-j} \beta_{i,t} + \sum_{j=1}^{p-1} \psi_{i,j}\, \Delta \ln y_{i,t-j} + \varepsilon_{i,t} \quad (5)$$

$$ECT_{i,t} = y_{i,t-1}\theta \quad (6)$$

where y represents the dependent parameter (CO^2), X denotes the independent parameters (GDPC, $GDPC^2$, $GDPC^3$, EC as well as REC) with equal amount of lags q through individual cross-sectional units i in time t, Δ represents the difference operator, ϕ denotes the adjustment coefficient, θ represents the long-run coefficient that yields β and ψ techniques after reaching convergence, and ε represents the error term.

The evaluations from the combined panel technique that is utilized in the analysis may not essentially reproduce the path of causality regarding the variables; thus, we deliver a causality technique report for the parameters in the present analysis following the significance of this technique in numerous empirical analysis (Saint Akadiri et al. 2019; Onifade et al. 2021; Alola and Kirikkaleli 2019; Çoban et al. 2020; Asiedu et al. 2021a, b; Gyamfi et al. 2021b, c; Bekun et al. 2021; Bekun and Gyamfi 2020). We show the Dumitrescu and Hurlin (2012) Granger causality technique for the analysis.

$$Y_{it} = \delta_i + \sum_{k=1}^{p} \beta_{1ik} Y_{i,t-k} + \sum_{k=1}^{p} \beta_{2ik} X_{i,t-k} + \varepsilon_{it} \quad (7)$$

From Eq. 7, β_{2ik} and β_{1ik} denote the regression coefficients and the autoregressive parameters for individual panel variable i at time t, respectively. Following the assumption of a balance panel of observation for the variable Y_{it} and X_{it} in the study, the null hypothesis of absence of causality among variables was tested against the alternative hypothesis of heterogenous causality in the panel observation.

Nevertheless, this analysis provides 3 empirical studies pathway: (i) stationarity estimation by fisher ADF and Pesaran et al. (2003) unit root techniques, (ii) cointegration studies and long-run estimation proposed by Pesaran et al. (1999) as well as Kao (1999), and (iii) causality technique from Dumitrescu and Hurlin (2012). Nevertheless, preliminary analysis of descriptive statistics and correlation analysis were analysis.

Empirical results and discussion

Table 3 shows the individual countries statistics of the variables in the model. It applies from these countries, i.e., Botswana, Congo Republic, and Mauritius, that GDPC has the highest mean, median, and maximum values, followed by CO_2 emission and energy consumption, while renewable energy consumption has the lowest mean, median, and maximum values. But from the analysis, the remaining countries (Benin, Cameroon, Cote d'Ivoire, Ethiopia, Ghana, Kenya, Nigeria, South Africa, and Zimbabwe) have CO_2 emissions having the highest mean, median, and maximum values, followed by real GDPC and energy consumption, whereas renewable energy consumption again have the lowest mean, median, and maximum values. It can also be observed from the correlation matrix that the real GDPC has a positive connection with CO_2 emission and energy consumption but have negative connection with renewable energy consumption. However, CO_2 emissions have a positive connection with energy consumption but have negative connection with renewable energy consumption. Nevertheless, renewable energy consumption has a negative connection with energy consumption.

It is imperative to conduct a stationarity check in econometric evaluation to prevent spurious error result (Gyamfi et al. 2020a; Adedoyin et al. 2020a; Adedoyin et al. 2020b). We find that all parameters in this study are first difference stationary after performing the unit root evaluation in Table 4. Based on this proof, it can be concluded that all series follow the order one [I (1)] identified by the ADF-Fisher unit root technique as well as the Im-Pesaran-Shin (Im et al. 2003) unit root technique. Consequently, our analysis examined the long-run association regarding the parameters. According to Johansen multivariate cointegration analysis and Kao residual cointegration test, there exist long-run (equilibrium relationship) among CO_2 emissions, economic development, energy consumption, and renewable energy consumption over the period considered which is presented in Table 5.

Cointegration results

After obtaining the long-run equilibrium among the variables from the cointegration techniques employed, the pooled mean group autoregressive distributed lag (PMG-ARDL) technique is employed to access both the long-run and short-run association of the independent variables (GDPC, $GDPC_2$, $GDPC_3$, REC, and EC) with the dependent variable (CO_2).

From Table 6, it is observed that there is a significantly positive connection regarding economic development

Table 3 Summary statistics

	Variable			
	CO_2	GDPC	EC	REC
Benin				
Mean	2783.546	703.0760	347.6884	69.82530
Median	2079.189	720.1683	340.2017	64.03772
Maximum	6318.241	833.6409	416.7958	94.98880
Minimum	707.7310	609.3456	288.7684	48.11725
Std. dev.	1844.290	66.17590	37.37534	17.34812
Skewness	0.585112	0.044067	0.351211	0.374816
Kurtosis	1.785607	1.921201	1.861829	1.583105
Jarque-Bera	2.962680	1.220390	1.863365	2.676603
Probability	0.227333	0.543245	0.393890	0.262291
Botswana				
Mean	3795.492	5330.827	1009.408	36.46557
Median	3828.348	5115.900	1008.742	34.24984
Maximum	7033.306	7574.282	1252.680	48.27315
Minimum	2636.573	3860.009	875.8318	27.16077
Std. dev.	965.2407	1113.427	88.90823	7.601983
Skewness	1.457325	0.447574	0.684141	0.377495
Kurtosis	6.127321	2.095754	3.753182	1.559986
Jarque-Bera	19.03679	1.686407	2.541126	2.753803
Probability	0.000073	0.430330	0.280674	0.252359
Cameroon				
Mean	4347.008	1230.177	387.4720	82.74594
Median	3861.351	1261.039	407.3618	84.37657
Maximum	7003.970	1428.216	425.1607	86.22745
Minimum	1103.767	1056.989	327.1993	76.97539
Std. dev.	1572.902	106.9472	34.54093	3.023921
Skewness	0.154325	−0.116899	−0.706045	−0.689942
Kurtosis	2.400058	1.983140	1.717956	1.936619
Jarque-Bera	0.474162	1.134027	3.789205	3.161310
Probability	0.788927	0.567217	0.150378	0.205840
Congo Republic				
Mean	1527.379	2542.995	329.1157	66.51143
Median	1279.783	2496.502	308.5225	64.94712
Maximum	3094.948	2922.973	552.4870	80.15296
Minimum	575.7190	2260.730	220.0657	55.14975
Std. dev.	748.1557	176.5809	102.1366	6.892188
Skewness	0.899241	0.460700	1.199471	0.496803
Kurtosis	2.696824	2.055409	3.297154	2.522155
Jarque-Bera	3.465056	1.813779	6.086694	1.266239
Probability	0.176837	0.403778	0.047675	0.530933
Cote d'Ivoire				
Mean	6925.643	1293.505	450.2868	72.81289
Median	6912.295	1298.844	406.9104	74.04173
Maximum	11045.00	1448.034	615.9285	78.89575
Minimum	4099.706	1138.665	351.6897	61.93085
Std. dev.	1698.207	82.86506	89.39258	4.367027
Skewness	0.659234	0.152358	0.515397	−1.264754
Kurtosis	3.486968	1.898325	1.830508	3.688367
Jarque-Bera	2.057810	1.360979	2.531507	7.158604
Probability	0.357398	0.506369	0.282027	0.027895
Ethiopia				
Mean	5069.994	248.9624	481.0338	38.33102
Median	4521.411	206.7431	480.2573	15.38972
Maximum	11598.72	452.7782	496.8146	84.71086
Minimum	2240.537	163.6233	470.4548	5.352098
Std. dev.	2513.239	84.59725	6.764422	34.48926
Skewness	1.106989	1.137763	0.742545	0.324656
Kurtosis	3.524336	2.989474	2.836064	1.269685
Jarque-Bera	5.392323	5.393883	2.325381	3.557915
Probability	0.067464	0.067411	0.312644	0.168814
Ghana				
Mean	7633.081	1094.650	335.9670	65.39311
Median	6992.969	1001.250	332.5276	65.67533
Maximum	14620.33	1659.797	415.6502	82.92838
Minimum	3817.347	823.5919	269.1488	44.04296
Std. dev.	2950.094	253.3587	46.14518	13.49564
Skewness	0.904172	1.039519	0.120435	−0.234453
Kurtosis	3.297404	2.917610	1.754287	1.623187
Jarque-Bera	3.498496	4.509571	1.676894	2.203633
Probability	0.173905	0.104896	0.432381	0.332267
Kenya				
Mean	9317.114	900.7794	451.9050	79.33573
Median	9369.185	871.4118	447.6357	79.51199
Maximum	14286.63	1075.659	513.4265	83.18299
Minimum	4840.440	823.0748	430.5163	75.51817
Std. dev.	2647.324	71.20203	17.34620	1.766197
Skewness	0.185851	1.071313	1.915171	−0.133071
Kurtosis	2.102037	3.127888	7.390145	3.035622
Jarque-Bera	0.983855	4.799168	35.35927	0.075105
Probability	0.611447	0.090756	0.000000	0.963144
Mauritius				
Mean	2850.579	6056.155	868.1231	24.19080
Median	2885.929	5738.056	886.7638	19.08307
Maximum	4228.051	9163.633	1111.422	47.06783
Minimum	1463.133	3707.857	629.3821	10.63386
Std. dev.	935.6462	1689.696	164.6635	12.06607
Skewness	−0.080593	0.353766	−0.080881	0.561802
Kurtosis	1.516410	1.894075	1.518532	1.755907
Jarque-Bera	2.319814	1.795490	2.313454	2.927348
Probability	0.313515	0.407487	0.314514	0.231385
Nigeria				
Mean	72753.28	1701.214	729.2415	86.28470
Median	85734.46	1374.437	721.9704	86.44863
Maximum	106068.0	2563.092	798.3031	88.83185

Table 3 (continued)

	Variable			
	CO_2	GDPC	EC	REC
Minimum	35199.53	1242.738	680.7101	82.95602
Std. dev.	27841.79	484.7689	33.22098	1.486974
Skewness	−0.273060	0.522165	0.271477	−0.443640
Kurtosis	1.255781	1.596788	2.053390	2.604349
Jarque-Bera	3.479737	3.187112	1.240490	0.983131
Probability	0.175543	0.203202	0.537813	0.611668
South Africa				
Mean	405209.7	6361.056	2539.191	17.25360
Median	386131.4	6045.963	2471.021	17.10719
Maximum	503112.4	7582.553	2913.130	19.12144
Minimum	301687.8	5423.588	2250.649	15.57029
Std. dev.	63303.96	787.9375	167.3074	0.999774
Skewness	0.029070	0.374701	0.455982	0.139475
Kurtosis	1.661897	1.489376	2.373535	1.907964
Jarque-Bera	1.868645	2.962071	1.275144	1.323288
Probability	0.392852	0.227402	0.528574	0.516002
Sum	10130242	159026.4	63479.76	431.3399
Zimbabwe				
Mean	12372.90	1041.028	792.6933	73.44431
Median	12020.43	1139.590	784.4768	74.29460
Maximum	17795.95	1347.972	952.6127	83.15371
Minimum	5603.176	593.1272	661.3148	63.74078
Std. dev.	3344.578	246.8250	87.73585	7.126531
Skewness	−0.200365	−0.278658	0.208219	−0.069603
Kurtosis	2.004305	1.614625	1.914718	1.358236
Jarque-Bera	1.199992	2.322777	1.407560	2.827883
Probability	0.548814	0.313051	0.494712	0.243183
	Correlation			
	LGDPC	LCO_2	LREC	LEC
LGDPC	1.000000			
LCO_2	0.284767	1.000000		
LREC	−0.354876	−0.267844	1.000000	
LEC	0.619828	0.717983	−0.550566	1.000000

Source: Authors compilation

(GDPC) and pollution (CO_2), as seen in findings of Gyamfi et al. (2020b) and Waqih et al. (2019). This study approves our claim that the nations that are in sub-Saharan Africa are placing a large focus on the environmental stewardship of their economies, particularly in the areas that we have studied. Many emerging economics which include the listed African nations have set economic expansion targets in contrast to environmental protection. In addition, the square of GDPC shows a negative significant association with pollution which affirms the existence of EKC in the estimation. This result affirms the finding of Hanif et al. (2019); Usman et al. (2019), Ike et al. (2020), and Destek and Sinha (2020) which their studies show the same invented U-shaped from their various analyses. The cubic GDPC proves the existence of N-shaped relation between income and pollution which is in agreement with the findings of Shahbaz et al. (2019) and Gyamfi et al. (2021a, b, c).

Table 4 Unit root result

	ADF-Fisher		Im-Pesaran-Shin	
	Level	Δ	Level	Δ
lngdpc	27.9965	68.5037***	68.5037	−4.8964***
lnrec	16.8419	67.8222***	0.7126	−5.0813***
lnec	22.1063	87.2054***	0.4049	−6.7569***
$lnCO_2$	27.2881	87.0290***	-0.46330	−6.7125***

Note: Superscripts ***, **, and* denote 1%, 5%, and 10% statistical rejection level, respectively, and the symbol Δ represents first difference. Worthy of mention here is that fitted mode is with intercept and trend

The result also indicates that environmental degradation and energy usage have positive significant association. The positive connection obtained regarding energy consumption and CO_2 emissions indicates that economic development of sub-Saharan African economics are energy-led growth attached on fossil fuel energy usage which has a great tendency of dilapidating the ecology of nations involved. This shows that most economics in African continent are still late to technological innovations that pave ways for clean production and economic performance. This affirms the studies of Acaravci and Ozturk (2010), Al-Mulali and Tang (2013), Jia et al. (2019), Udemba and Agha (2020), Sharif et al. (2020), Sarkodie and Ozturk (2020), and Usman et al. (2020a, b). Lastly, a negative with significant 1% level relationship is recognized among renewable as well as CO_2 emission. It has been found that transition to more conservative (renewable) sources of energy guarantees better of environment irrespective of the location of the economy. This aligns with the findings of Dogan et al. (2017), Sebri and Ben-Salha (2014), and Usman et al. (2020b).

Our outcome from the short-run error correction with regard to the coefficient shows negatively robust at 1% significant level. This could be deduced that any disorder in the long-run equilibrium regarding the parameters under study will be corrected at a pace of 54 % yearly. Again, from the short-run analysis, only renewable energy consumption have a 10% significant connection with CO_2 emission.

Heterogeneous causality test

The causality outcome is reported in Table 7 which shows a feedback causality regarding economic development and pollution as well as renewable energy consumption and economic

Table 5 Johansen multivariate cointegration analysis

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat (from max-eigen test)	Prob.
r≤0	120.2***	0.0000	106.9	0.0000
r≤01	42.39**	0.0117	36.97	0.0441
r≤0 2	22.11	0.5728	21.32	0.6198
r≤03	24.38	0.4403	24.38	0.4403
Kao Residual cointegration Test				
			t-Statistic	Prob.
ADF			-1.539135*	0.0619
Residual variance			0.002041	
HAC variance			0.003131	

Note: Superscripts ***, **, and * denote 1%, 5%, and 10% statistical rejection level, respectively

development. Nevertheless, there is a one-way causality regarding economic development and energy consumption, renewable energy consumption and pollution, energy consumption and pollution, as well as energy consumption and renewable energy consumption.

Conclusion and policy implications

Carbon emission is a major cause of global warming. Major strategies have been put in place to reduce this major issue throughout the world in which the sub-Saharan African

Table 6 Long- and short-run analysis. Estimated model CO_2 =f(GDP, GDP^2, GDP^3, REC, EC). PMG-ARDL (1, 2, 2, 2, 2, 2)

Variable	Coefficient	Std. Error	T-Statistic	Prob.
Long-run equation				
LGDPC	17.82932***	5.503869	3.239415	0.0015
$LGDP^2$	−2.240757***	0.726014	−3.086383	0.0024
$LGDP^3$	0.094325***	0.031552	2.989482	0.0033
LREC	−0.157118***	0.043447	−3.616332	0.0004
LEC	1.575243***	0.117632	13.39125	0.0000
Short-run equation				
ECT(-1)	−0.539920***	0.129843	−4.158240	0.0001
(LGDPC)	3779.420	6032.795	0.626479	0.5319
D(LGDPC(-1))	−15872.84	10959.59	−1.448306	0.1496
D(LGDPSQ)	−505.0360	848.3301	−0.595330	0.5525
D(LGDPSQ(-1))	2140.787	1477.010	1.449406	0.1493
D(LGDPCUBE)	22.36459	39.88923	0.560667	0.5759
D(LGDPCUBE(-1))	−96.34510	66.73828	−1.443626	0.1509
D(LREC)	−1.306487*	0.702730	−1.859158	0.0650
D(LREC(-1))	−0.263376	0.383757	−0.686309	0.4936
D(LEC)	0.318427	0.415014	0.767269	0.4441
D(LEC(-1))	−0.590296	0.591147	−0.998561	0.3196
Constant	−25.98702***	6.399024	−4.061091	0.0001
Diagnostic test				
Mean dependent var	0.045607	S.D. dependent var		0.166882
S.E. of regression	0.120430	Akaike info criterion		−1.550484
Sum squared resid	2.190002	Schwarz criterion		0.289061
Log likelihood	381.5727	Hannan-Quinn criteria		−0.814296

Note: Superscripts ***, **, and * denote 1%, 5%, and 10% statistical rejection level, respectively

Table 7 Dumitrescu and Hurlin panel causality results

Null hypothesis	W-Stat.	Zbar-Stat.	P-value
$LCO_2 \neq LGDPC$	4.44247***	2.97693	0.0029
$LGDPC \neq LCO_2$	7.82628***	7.57147	4.E-14
$LREC \neq LGDPC$	3.80996**	2.11811	0.0342
$LGDPC \neq LREC$	6.43547***	5.68303	1.E-08
$LEC \neq LGDPC$	2.44050	0.25866	0.7959
$LGDPC \neq LEC$	5.81236***	4.83697	1.E-06
$LREC \neq LCO_2$	4.63019***	3.23182	0.0012
$LCO_2 \neq LREC$	2.75664	0.68792	0.4915
$LEC \neq LCO_2$	7.90933***	7.68424	2.E-14
$LCO_2 \neq LEC$	2.90467	0.88890	0.3741
$LEC \neq LREC$	5.90625***	4.96445	7.E-07
$LREC \neq LEC$	3.41410	1.58062	0.1140

Note: Superscripts ***, **, and * denote 1%, 5%, and 10% statistical rejection level, respectively; the symbol ≠ depicts null hypothesis of does not Granger cause

countries are not left out. Thus, the effort in the current study should provide real information on whether the emission-income association presents an inverted U-shaped EKC or N-Shaped EKC and if so, when the turning point(s) will be reached. For this reason, the authors investigated the sub-Saharan African countries emission-income association by incorporating renewable energy consumption and energy consumption as control variables from 1990 to 2016. This study leverages on pooled mean group autoregressive distributed lag (PMG-ARDL) technique that corrects for cross-sectional dependency and heterogeneity to achieve the robustness of empirical outcomes. To this point, the ADF-Fisher unit root technique as well as the Im-Pesaran-Shin unit root technique proofed stationarity at order one [I(1)] among the variables. Moreover, Johansen multivariate cointegration analysis and Kao residual cointegration test all indicated a long-run equilibrium relationship among the variables. The main conclusions from the results of the study are as follows:

Economic development contributes to growth of CO_2 emission in sub-Saharan African countries. Again, the square of economic development shows a negative significant association with pollution which affirms the existence of EKC in the estimation. Therefore, an invented U-shape was validated for the analysis. The cubic GDPC proved the existence of N-shaped relation between economic development and pollution. Moreover, the coefficient of renewable energy consumption is negative and statistically significant at 1% level in the sub-Saharan African countries. The coefficient of energy consumption is also positive and statistically significant at 1% level in the sub-Saharan African countries. From the short-run analysis, only renewable energy consumption had a 10% significant connection with CO_2 emission.

Moreover, a feedback causality runs from economic development and pollution as well as renewable energy consumption and economic development. Nevertheless, a one-way causality runs from economic development and energy consumption, renewable energy consumption and pollution, energy consumption and pollution, as well as energy consumption and renewable energy consumption

Policy implication

Considering the results of the analysis, certain significant strategy can be concluded. It is necessary for policy-makers to consider rising energy intensity as part of anti-emission initiatives. Developing countries are facing difficulties in delivering electricity as well as improving access to renewable energy and at the same time optimizing the protection of these substitutes. At the present time, states are making big efforts to curb environmental issues to prevent its negative effects on developed and emerging areas. This process may also optimize the inspiration and contributions of the participating countries. Countries chosen for this initiative are blessed with sustainable energy resources which have been ignored by both the country and its people. The usage of non-renewable energy, which produces carbon, is a significant driving force of energy usage in emerging economies. As stated by Shahbaz et al. (2013), some countries in this analysis that are within the southern part of Africa are heavily dependent on coal for electricity. Moreover, Africa as a continent is expected to provide more than 1750 terawatt hours of hydropower and 14,000 megawatts of geothermal sources with just 7% of the overall capacity being exploited (Shahbaz et al. 2013). The goal is to use green market to foster prosperity. Besides hydroelectric power and geothermal, there are other environmentally friendly energy options that can be used in households such as biofuels and biomass. Energy politics among these developing economics are particularly crucial because of the uneven distribution of resources in developing countries. It is a burden on everyone, including people within these countries, to be part of the endeavor to fight global warming. This is critical because government's knowledge and communication campaigns need to be developed to foster understanding on environmental concerns and educate people how to reduce greenhouse gas emissions. The national and regional governments need to support afforestation and landscaping for reducing pollution on a continent (APF 2009). Furthermore, energy intensity maintains a vital consideration to ensure that currently and in the future "basic needs" are fulfilled as well as to fulfil the world's sustainability targets. For all these purposes, climate and energy industries should be given due consideration to becoming more ecologically responsible. Taking into account all these considerations, it is important to enforce technical growth policies involving government support, expenditure on R&D initiatives, and funding by indirect steps such as tax cuts.

The implication of the EKC in the selected developing countries for the carbon emission means that these countries need to minimize environmental degradation on its trajectory for increased income level. Given that these countries are still very much emerging on their growth path. The need to fortify institutional apparatus is needed to enact effective environmental strategies and regulations to achieve environmental sustainability without compromise for economic development. Therefore, the need for a transition to renewables is pertinent given the advantages of a cleaner environment. As such there should be concerted efforts on part of all stakeholders and government officials for a paradigm shift to clean energy technologies by substituting the countries' share of their energy mix from conventional energy of fossil fuel to clean energy sources.

Appendix

Table 8 List of countries

Benin	Ghana
Botswana	Kenya
Cameroon	Mauritius
Congo, Rep.	Nigeria
Cote d'Ivoire	South Africa
Ethiopia	Zimbabwe

Availability of data and materials Not applicable

Author contribution Andrew Adewale Alola: Formal analysis, methodology, and corresponding author

Festus Victor Bekun: Conceptualization draft, investigation, and data curation

Bright Akwasi Gyamfi: Writing-original draft

Asiedu Benjamin Ampomah: Writing

Declarations

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