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RESEARCH ARTICLE

The impact of natural resource consumption on carbon emissions: evidence of a symmetric and asymmetric effect from Sub-Saharan Africa

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Abstract

Sub-Saharan African countries are among mineral-rich developing countries strategically competing to guarantee sustainable economic development through resource exploration. The possibility of increasing the level of carbon emission due to using low-cost fuels and high pollutants during mineral resource extraction activities leading to environmental degradation continues to draw the attention of researchers and policy makers. This research aims to analyze the response of carbon emissions in the African continent to symmetric and asymmetric shocks on resource consumption, economic growth, urbanization, and energy consumption. Following the Shin et al. (2014a) linear and nonlinear autoregressive distributed lag (ARDL) methodology in panel form, we construct symmetric and asymmetric panel ARDL–PMG model to evaluate both short- and long-run impacts of resource consumption on carbon dioxide emissions for a panel of 44 African countries over the period 2000–2019. The symmetric results show that the effect is not statistically significant despite natural resource consumption positively impacting carbon emission in the long and short runs. Energy consumption was found to affect environmental quality in the long and short runs adversely. Interestingly, economic growth was found to improve environmental quality in the long run significantly, and no significant impact was reported in the case of urbanization. However, the asymmetric results prove that a positive and negative shock to natural resource consumption contributes significantly to carbon emission, contrary to the insignificant impact established in the linear framework. The gradual growth in the manufacturing sector and an expansion in the transportation sector in Africa led to high demand and consumption of fossil fuels. This possibly accounts for the adverse effect of energy consumption on carbon emissions. Most African countries depend mainly on exploring natural resource endowment and agricultural activities to drive the growth of their economies. Due to the weak environmental regulatory frameworks in most African countries and public corruption, multinational companies (MNCs) in the extractive sector do not adhere to environmentally friendly activities. The majority of African countries are also battling illegal mining activities and illicit felling of trees, which may account for the positive relationship between natural resource rents and environmental quality reported. In terms of policy implications of the study, governments in Africa must preserve natural resources, use environmentally friendly and technologically advanced resource extraction methods, opt for green energy, and strictly apply environmental laws to promote environmental quality on the continent.

Keywords Carbon emission · Energy consumption · Natural resource · Economic growth · Urbanization · Environmental quality

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Introduction

Climate change has been a substantial challenge for humanity in recent years. A major contributing factor identified as causing climate change is human activities which are not showing any signs of improvement over the past years (Joshua and Bekun 2020; Magazzino et al. 2020; Ulucak and Khan 2020)

Environmental degradation resulting from human activities is gradually becoming an important topic for debate among researchers and analysts from numerous fields. This is due to the adverse effects of greenhouse gas emissions on the world's sustainable development. Identifying greenhouse gas emissions by experts as the leading cause of climate change is critical in curbing climate change's menace on the planet. Franco et al. (2017) observed that carbon emissions contributed to approximately 60% of global warming, making it a massive component of greenhouse gases.

Meanwhile, the economy of every country hinges on the environment to provide resources; hence, making policies to cater for sustainable development remains crucial. Aiming for economic growth only will have some ramifications for the globe and its living organisms, which comprises humans as well. The need for continuous growth and uncontrolled consumption of resources has already caused irreversible destruction to the planet (Bradshaw et al. 2010).

This modern era has been characterized by increased competition among developing and developed countries. In the interim, developing countries also desire to expand their economic activities through urbanization, industrialization, and increasing production to sustain their economies and eradicate poverty. In pursuance of economic growth, these activities increase the demand and consumption of energy. In the long run, this would lead to an increase in carbon dioxide (CO_2) emissions, which is hazardous to the health of humans and sustainable development (Asongu and Odhiambo 2019). Due to climate change and carbon dioxide emissions at the global and regional levels, developing countries are faced with issues of cyclones, rising sea levels, floods, and drought. Understanding the dangers associated with the rise in carbon emissions and climate change would be crucial for developing countries since they have been identified as lacking the resources to help them recover from its adverse effects (Nyang'au et al. 2020).

Despite some sustained economic growth for nearly two decades, Sub-Saharan Africa (SSA) continues to be one of the world's poorest regions, with excessive dependence on the region's natural resources (Bank 2016). Ranging from freshwater, arable land, oil, minerals, natural gas, wildlife, forest, and so on are some of the rich natural resources the region has endowed with and relies upon to achieve sustainable development goals (SDGs). The fourth issue of the *Sustainable Development Report on Africa* reports that managing and regulating this broad range of natural resources are essential for the region's path toward sustainable development outcomes (Morley 2015). Nonetheless, it is relevant to state that the sub-region's economic growth process, which is based on the rise in the demand for natural resources combined with the unsustainable exploitation of natural resources from various emerging countries, has rekindled the discussion about the significant role natural resource exports and consumption play in the achievement of the SDGs in countries with rich resources (Islam and Managi 2019; Merino-Saum et al. 2018; Sahin et al. 2019; Sinha and Sengupta 2019)

Furthermore, Balsalobre-Lorente et al. (2018), in a study, revealed that natural resources inhibit the usage of some high-pollutant fossil fuels by reducing their import and allowing a feasible alternative to change to low-pollutant energy resources like natural gas. Some empirical studies have supported this notion. In addition, Zafar et al. (2019) found in their research that in the USA, natural resources have restrained environmental degradation, and similar outcomes were also observed in BRICs (Brazil, Russia, India, China) economies (Danish et al. 2019).

However, on the contrary, Ahmed et al. (2020a), in a study, revealed that since mining activities destroy the environment, the abundance of natural resources pollutes the environment. The likelihood of using high-pollutant, low-cost fossil fuels is exceptionally high for SSA countries, making it difficult to exploit the environmental benefits of abundant natural resources. Likewise, Sarkodie and Adams (2018) observed that mining, chain saw operations, and deforestation are primary causes of environmental pollution and loss of natural habitat. Further studies by Zafar et al. (2020) admitted that economic development, which is associated with urbanization and industrialization, stimulates the exploration of natural resources. This will ultimately increase the degradation of the environment. From this, it is evident that previous studies have observed diverse perspectives and disagreements about whether abundant natural resources are harmful to the environment.

Furthermore, in previous studies, factors such as economic development, energy consumption, and urbanization were considered when assessing the influencing factors of environmental quality (Shafiei and Salim 2014). These key factors have undergone tremendous changes in SSA countries in recent times. Energy consumption does have huge effects on economic growth, the reduction of poverty levels, and sectoral development (Adedoyin et al. 2020a; Adedoyin et al. 2020b; Kirikkaleli et al. 2021; Udi et al. 2020).

The consumption of energy contributes to attaining high levels of economic development and is viewed as critical for the needs of humans. Even though it is generally consumed in various forms, the consumption of energy has frequently been on the rise (Petroleum 2017). On the other hand, urbanization and economic growth have been observed to be significant contributors to the unusual increase in energy consumption, specifically non-renewable energy (Ahmad et al. 2019; Wu et al. 2019). Studies have revealed that non-renewable energy is a finite pollutant and associated with various health hazards (Ali et al. 2020; Destek and Sarkodie 2019; Feron et al. 2019; Wang and Dong 2019). Hence, the need to improve environmental quality by reducing greenhouse gases has brought up the appeal for the adoption of renewable energy by several researchers (see Ahmed et al. 2020b; Asongu et al. 2020; Destek and Sinha 2020; Ibrahiem 2020; Khan et al. 2020; Magazzino et al. 2020; Sharif et al. 2020b; Vélez-Henao 2020). Renewable energy is clean energy and is characterized by low levels of emissions (Maji et al. 2019; Nathaniel and Bekun 2021; Nguyen and Kakinaka 2019).

We attempt to make significant contributions to the extant literature by being, as far as we know, the first article to examine the cointegration between natural resource consumption and environmental quality for a large panel of 44 African countries. Second, considering that the relationship may be asymmetric, as far as we know, this research is the first to examine the nonlinear relationship between natural resource consumption and carbon emission by employing a nonlinear PMG-ARDL approach. Past studies that assessed this link either for some panel countries (see, for example, Akinlo 2008; Balsalobre-Lorente et al. 2018; Bekun et al. 2019; Danish 2019; Khan et al. 2021; Wang et al. 2020; Wolde-Rufael and Idowu 2017) or for some individual countries see (for example, Aeknarajindawat 2020; Baloch and Suad 2018; Khan et al. 2021; Kwakwa Paul et al. 2020; Shen et al. 2021a) assumed a symmetric relationship between natural resources and carbon emissions. According to Shin et al. (2014a), among social sciences, an endemic phenomenon is nonlinearity, and for that matter, asymmetry is fundamental to the human condition. This position was further elaborated by Granger and Yoon (2002), who also noted that a time series might have a hidden cointegration if positive and negative series are cointegrated. If a nonlinear relationship is confirmed between the variables, the previous authors might have arrived at incorrect conclusions due to the misspecification of models employed. This probably accounts for the conflicting results reported by various researchers. The current research emphasizes the need to examine the cointegration between natural resource consumption and carbon emission in symmetric and asymmetrical cointegrating relationships. The African continent is heavily endowed with natural resources. The issue of its conservation or exploration is an interesting area for research since it links with environmental quality. However, despite the growing body of literature on the subject, the extant literature has shown that very few studies were conducted on the nexus between natural resource consumption and carbon emission. The essence of investigating the nonlinear cointegration in the relationship between natural resource consumption and carbon emission in Africa is due to political, technological, and economic factors that affect the exploration and consumption of natural resources. Resource booms lead to increased demand and consumption, while political instabilities and a decline in global commodity prices can adversely affect the consumption of natural resources. These phenomena form the basis to consider the impact positive shocks and negative shocks to resource consumption can have on environmental quality on the continent.

The remaining portion of the paper is arranged as follows. The second section of the article includes a detailed review of previous literature. The third section explains the empirical modeling, methodology, and data. The fourth section analyzes the empirical results and detailed discussions of the findings. The fifth section, the last section, delivers the conclusions from the study's findings and provides some policy implications.

Literature review

The current study examines the role of natural resource consumption, economic development, energy consumption, and urbanization in SSA countries' environmental quality. The literature is divided into four sections to elaborate on the relationship between the variables.

Nexus between natural resources and CO_2 emissions

Several studies have investigated the nexus between natural resources and CO_2 emissions by incorporating numerous econometric models for time series and panel data. Nonetheless, mixed outcomes were found in these studies concerning natural resources and CO_2 emissions. Bekun et al. (2019) assessed the impact of energy consumption, natural resource rent, and economic growth on CO_2 emissions for sixteen European Union countries. With the panel mean group method applied to the data, which covers a period from 1996 to 2014, the authors observed that energy consumption, natural resource rent, and economic growth had a long-term adverse effect on the quality of the environment of the European Union countries. Moreover, the impact of economic growth, natural resources, and energy consumption on Pakistan's CO_2 emissions was examined by Baloch and Suad (2018) from 1990 to 2013. The authors used the autoregressive distributive lag (ARDL) technique to establish that natural resources have a negative effect on environmental quality.

Aeknarajindawat et al. (2020) also found that natural resources positively affected CO_2 emission when they applied the autoregressive integrated moving average approach to data for Malaysia covering 2008 to 2017. Kwakwa et al. (2020) assessed the effect that natural resource extraction has on CO_2 emissions in Ghana from the period 1971 to 2013. The authors found that the extraction of Ghana's natural resources increased energy consumption and CO_2 emissions, thus reducing the environmental quality. Shen et al. (2021b) used the cross-sectional augmented autoregressive distributed lags (CS-ARDL) techniques to investigate the nexus between natural resources investment and CO_2 emissions in China. The authors used data from 1995 to 2017 and established that natural resources positively affect CO_2 emissions. A more elaborative study on China was conducted by Umar et al. (2020) to examine the nexus between determinants of CO_2 emissions from 1980 to 2017.

Similarly, the authors revealed that China's natural resources have a positive relationship with its CO_2 emissions. Moreover, Wang et al. (2020) examined the role financial development and natural resources play in regulating the emissions of CO_2 for the G-7 economies. The empirical findings from the study revealed that both economic growth and natural resources cause an increase in CO_2 emissions.

In contrast, natural resources and renewable electricity were observed to reduce CO_2 emissions in a study conducted by Balsalobre-Lorente et al. (2018). The authors found these revelations when they used the panel least squares (PLS) model to investigate the effect electricity, natural resources, and economic growth had on CO_2 emissions for five European Union countries. Moreover, Khan et al. (2021) observed that natural resources could be used to regulate CO_2 emissions in the USA. Shahabadi and Feyzi (2016) also observed that natural resources combined with the attraction of foreign direct investment (FDI) contribute to environmental quality in developed countries. When investigating the nexus between natural resource abundance and environmental degradation, the authors made this observation. Interestingly, Bekun et al. (2019) established that total natural resource rents minimize CO_2 emissions only in the short run, while natural resource rent has a positive relationship with CO_2 emissions in the long run. Danish et al. (2019) also observed dynamic relationships between natural resource abundance and CO_2 emissions for the BRICS countries when they applied the augmented mean group (AMG) model to data covering from 1990 to 2015. The results from the study showed that natural resources reduce pollution in Russia, but in South Africa, it contributes to CO_2 emissions. By far, the empirical findings from previous literature can be observed to be inconclusive when it comes to the effect of natural resources on environmental quality, particularly in the SSA countries.

Nexus between energy consumption and CO_2 emissions

Muhammad (2019) applied both the generalized method of moments (GMM) and system (GMM) techniques to examine the nexus between economic growth, CO_2 emissions, and energy consumption for the Middle East and North African (MENA) countries. The author's result showed that in the long run, an increase in energy consumption has an adverse effect on environmental quality. Moreover, a bidirectional causality link was found between energy consumption and CO_2 emissions in Kuwait in a study by Wasti and Zaidi (2020), who also applied the ARDL and Granger causality test. Similarly, Alola et al. (2019) incorporated the PMG-ARDL technique to examine the relationship between energy consumption and ecological footprint for fourteen European countries. The authors found that during the study period, the consumption of non-renewable energy reduces environmental quality. The consumption of renewable energy also does not improve environmental sustainability. Another study by Bhat (2018) used the panel ARDL method to investigate the effect of economic growth and energy consumption on carbon dioxide for a period spanning from 1996 to 2016. The results revealed that non-renewable energy consumption increases CO_2 emissions. A similar outcome was confirmed by Sulaiman and Abdul-Rahim (2017) when they applied the ARDL model to assess the nexus between CO_2 emissions, economic growth, and energy consumption in Malaysia from 1975 to 2015.

In contrast, the usage of the quintile ARDL approach by Sharif et al. (2020a) to examine the effect of Turkey's energy consumption on its ecological footprint over the period 1965 to 2017 found the consumption of renewable energy improves the quality of the environment in the long run. With the application of the dynamic least squares (DOLS) and fully modified least squares (FMOLS) on 65 belt-and-road countries, Rauf et al. (2020) also observed that renewable energy and financial development improved environmental quality when the authors were investigating energy consumption and ecological challenges. Destek and Sinha (2020) used data from Organization of Economic Co-operation and Development (OECD) countries from 1980 to 2014 to study the relationship between renewable energy, non-renewable energy, and ecological footprint. The authors observed that renewable energy increases environmental quality, while non-renewable energy increases environmental degradation. Hanif (2018) similarly found that renewable energy helps reduce the emissions of CO_2 and consumption of fossil fuels rather than increases CO_2 emissions when the author investigated the impact of urban expansion, economic growth, and energy consumption on CO_2 emission in SSA countries.

Liu et al. (2022a) employed the quantile regression methodology to determine the link between renewable energy consumption, technological innovation, and the quality of institutions in formulating SDG policies for emerging nations. They found an inverse relationship between renewable energy consumption, technological innovations, institutional quality, and carbon emission. Economic growth and population also contributed to carbon emissions in the sample studied. Anwar et al. (2022) reassessed how technological policies, economic development, and the quality of institutions influence the reduction of environmental degradation in emerging seven (E-7) countries using panel quantile regression from 1996 to 2020. They reported that renewable energy consumption, technological innovation, and the quality of institutions contribute to reducing carbon emissions in the panel studied. Economic growth and population were however found to increase the carbon emission. Analyzing the asymmetric effect of green innovation, renewable energy, and globalization on sustainable environment using a novel model, method of moment quantile regression (MMQR), Sun et al. (2022a) in their findings reported that globalization is a contributor to carbon emissions while renewable energy consumption is associated with a decline in carbon emissions. Habiba et al. (2022) further assessed the link between financial development, green technology innovations, renewable energy, and carbon emissions among the top twelve emitters from 1991 to 2018 using the Dumitrescu and Hurlin (D-H) causality test. Results, as presented, revealed financial development contributes to an increase in carbon emissions. However, renewable energy and green technology innovations were found to reduce carbon emissions. Edziah et al. (2022), in a study of 18 Sub-Saharan African countries, sought to establish the influence exogenous technological factors play in carbon emissions. Their research findings reported revealed that renewable energy consumption and machinery imports accounted for a decline in carbon emission in the sample analyzed. Notably, a positive link between R&D and carbon emission was identified in the sampled region. Liu et al. (2022b) integrated environmental innovation in modeling the nexus between public-private partnership and transport emissions. Using the quantile ARDL (QARDL) technique, the authors found that public-private partnership and environmental innovation decrease carbon emissions at various quantiles.

Nexus between urbanization and CO2 emissions

The role of urbanization in the growth of a country's environmental profile is crucial, and it can be a deciding factor for the entire concept of a nation's green environment. Yuan et al. (2019) identified urbanization as an important cause of noise pollution, which harms the environment. This situation worsens when many people relocate to the urban areas and tackle the congestion issue, i.e., construction of high-rise residential buildings, which eventually increases noise pollution. The study recommended policymakers ensure owners of residential buildings consider spatial building designs to resolve challenges of the environment. In Tunisia, Farhani and Ozturk (2015) observed that urbanization and financial development increase CO2 emissions, while trade openness contributes to the reduction in the emissions of CO_2. Another study was done by Martínez et al. (2018) to investigate the understanding of urbanization concerning the mitigation of environmentally degrading activities. The results of the study revealed that urbanization does play a role in climate change. Furthermore, Ahmed et al. (2019) analyzed the nonlinear relationship between CO_2 and urbanization for Indonesia with data spanning from 1971 to 2014 while also controlling for economic growth and energy intensity. The authors established from their results that energy intensity, urbanization, and economic growth all have a positive relationship with CO_2 emissions in Indonesia.

Indonesia was again chosen as a study area by Kurniawan and Managi (2018), who examined the impact of urbanization and trade on the consumption of coal for the period 1970 to 2015. The study results showed that both urbanization and trade increase coal usage, thereby reducing the environmental quality. This prompted the authors to recommend policies that ensured the reduction in coal consumption in Indonesia for the environment to be sustainable. Shahbaz et al. (2019) found in their study that urbanization and globalization positively affect emissions, while trade and institutional quality reduce environmental degradation. Using data covering 1997 to 2016 for 30 Chinese provinces, Li et al. (2019b) investigated the effects of modernization on CO_2 emissions in China. The authors discovered that during the study period, urbanization positively affected CO_2 emissions. Duan et al. (2022) initiated the decoupling method to explore the decoupling relationship between demographic, spatial, economic and social urbanization, and carbon emissions in 33 African countries. The results show that all four types of urbanization adversely affect carbon emissions within the study period. The relationships among renewable energy consumption, urbanization, economic growth, and carbon emissions in the MENA region from 1991 to 2019 was investigated by Sun et al. (2022b) using continuously updated fully modified and bias-corrected methods. The results indicated that rapid urbanization and economic growth contributed to higher carbon emissions.

Similarly, urbanization and energy consumption in high-income countries were found to have a positive correlation with carbon emissions when Azizalrahman (2019) explored the impact urbanization has on carbon emissions with a comparative analysis of lower-middle income, upper-middle income, and high-income groups of countries. More studies also support the negative relationship between urbanization and CO_2 emissions (Fan and Zhou 2019; Wang and Zhao 2018; Wang et al. 2019). In contrast, Lin et al. (2017) and Adams and Klobodu (2018) found that urbanization had no significant effect on carbon emissions in low-income countries and Africa, respectively, while economic growth significantly contributed to CO_2 emissions.

Nexus between economic growth and CO_2 emissions

Numerous studies have been conducted on the nexus between economic growth and environmental degradation. Grossman and Krueger (1995) advanced the theory of the environmental Kuznets curve (EKC), which was first developed in the 1950s to 1960s by the economist Simon Kuznets. This hypothesis established that as an economy grows at an early stage, it has an adverse effect on the environmental quality just for it to reduce the emissions of harmful gases at a later stage after the turning point. Selden and Song (1994) associated this phenomenon with environmental awareness. This implies that the evolution of economic development and its impact on the quality of the environment is conveyed through a U-shaped function (Stern 2004). Since then, there have been different opinions surrounding this theory.

Some experts have the opinion that a country's economic development does have a positive impact on the reduction of its CO_2 emissions. They assume that the growth in the economy results in technological development. Thus, companies allocate money for improvements in their practices, allowing them to improve efficiency and compete in the market. Moreover, since the global warming situation is now being treated as urgent and support projects and programs regarded as environmentally friendly. For instance, in a study by Lanoie et al. (1998), the authors revealed that the market could reduce the emissions of CO_2 simply by stimulating companies to conform to environmental regulations. Studies such as Birdsall and Wheeler (1993), Frankel and Rose (2002), and Frankel and Romer (1999) support this hypothesis which established that the growth of an economy could cause environmentally friendly technology to be implemented, which will result in the reduction of CO_2 emissions. Bello and Abimbola (2010), Islam et al. (2013), and Wang and Jin (2007) affirm that economic growth will alert companies to incorporate laws regarding the protection of the environment. Another study by Kumbaroğlu et al. (2008) implied that economic growth contributes to the ease in developing the technological domain to reduce CO_2 emissions. Other studies that have tested and confirmed the presence of the EKC curve for different countries are Acaravci and Ozturk (2010) for European countries, Apergis and Ozturk (2015) for Asian countries, and Aldy (2005) for specific states of the USA.

However, other studies observed that economic growth instead increases the level of pollution. They reveal a negative relationship between these 2 study variables. Tamazian et al. (2009) claimed that the level of emissions of CO_2 demonstrates every country's economic growth, implying that the fastest-growing countries have the most significant levels of energy consumption and thus emit the highest levels of CO_2. The study further attributed economic growth as the main factor in the increase of CO_2 emissions and pollution. In the case of Indonesia and Malaysia, Shahbaz (2009) admitted in their study that although private sector investment contributes to the reduction in CO_2 emissions, foreign investments still cause an increase in the emission of this harmful gas. Also, results from a study by Chebbi et al. (2011) show how economic development has adverse effects on the level of pollution. Abbasi and Riaz (2016) further linked the growth in the emission of CO_2 to the economic blooming of the private sector. A similar conclusion was made by Jalil and Feridun (2011) when they conducted research using China as a case study. Yang et al. (2012) claimed that studies concerning the evolution of the EKC only showed the influence of economic development on pollution rather than concentrating on the dynamic relationship between the two variables. Employing the STRIPAT and quantile regression models, Wen et al. (2022) investigated the asymmetric effect of ICT, economic growth, population, renewable energy consumption, and financial development on carbon emissions in MINT nations.

Findings from the study revealed that ICT and renewable energy adversely affect carbon emissions. In contrast, population, economic growth, and financial development contribute positively to carbon emissions from 1990 to 2018. Anwar et al. (2022) conducted empirical studies using data from E7 countries and applying quantile regression to analyze the heterogeneous effect of technological innovation, the quality of institutions, population, trade openness, per capita income, and population. Reported findings revealed an inverse link between the quality of institutions, technological innovation, and carbon emissions. Whereas, economic growth was also found to lead to environmental unsustainability in E7 countries. In another study, Anwar and Malik (2021) investigated the impact of technological innovation and the quality of institutions on environmental deterioration among the G-7 countries. Economic growth and population were identified as contributing to the surge in carbon emissions. In contrast, the quality of institutions, technological innovation, and renewable energy account for a decline in environmental degradation. In a panel study using 141 countries divided into upper, middle-, and lower-income countries to assess the effects of economic globalization on energy efficiency, Liu et al. (2023) revealed that economic globalization improves energy efficiency only in upper-middle- and lower-middle income countries and not in high- and lower-income countries.

Data and methodology

Data description

In the empirical segment of our research, we analyze the total natural resource rents and carbon emission relationship, thus the effects of total natural resource consumption and environmental quality in Africa. Our dependent variable is CO_2 emission averaging 22.767 MMtonnes. We include significant determinants of carbon emission based on existing literature as follows: urbanization (urban population), GDP per capita (current US$) to proxy economic growth, and total natural resource rents (% of GDP) as a proxy for natural resource consumption. The World Bank computes total natural resource rents as the sum of natural gas rents, oil rents, coal rents (hard and soft), forest rents, and mineral rents. We also use energy consumption qbtu (quadrillion British thermal units) as an additional regressor. All variables are naturally log transformed to enable the interpretation of coefficients as elasticity. Energy consumption and carbon emission data were sourced from US Energy Information Administration (EIA). We obtained GDP per capita, total natural resource rents, and urbanization data from the World Bank Development Indicators (WDI) database. Our data set covers annual data from 2000 to 2019 for 44 African countries. Data availability dictated the choice of the period and countries employed for the research. The panel of countries used for the study is Angola, Benin, Botswana, Burkina Faso, Burundi, Carbo Verde, Cameroon, Chad, Central African Republic, Comoros, Congo Republic, Congo DRC, Ivory Coast, Djibouti, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

Research method

Using a panel data model to examine the association between total natural resource consumption and carbon emission has numerous benefits in empirical studies. For instance, it assists in simultaneously considering the cross-sectional characteristics between countries. It captures the dynamic interconnection between the total natural resource rents and carbon emissions. Furthermore, there is higher efficiency in estimations due to an increase in the degree of freedom due to many observations. Interpreting estimation results generated from analysis for cross-sectional data or panel time-series data is more comprehensive. Therefore, we employed the panel model pooled mean group (PMG) ARDL proposed by Pesaran et al. (1999), which is noted to take into consideration a lower magnitude of heterogeneity, as it applies homogeneity in the long-run coefficients while simultaneously allowing heterogeneity in the short-run coefficients as well as the error variance. It also allows a combination of $I(0)$ and $I(1)$ stationary variables and does not allow $I(2)$ variables. Our study involves 44 cross-sections and 20-year time series, which the model can well take care of since it can be applied even in the case of a small sample size.
We select the regressors of carbon emission following a similar study by Altinoz and Dogan (2021). Following this study, the empirical linkages between carbon emission and resource consumption, GDP per capita, urbanization, and energy consumption are formulated using the following linear equation:

$$CO2_{it} = \beta_0 + \beta_1 NRR_{it} + \beta_2 URB_{it} + \beta_3 EC_{it} + \beta_4 GDPPC_{it} + \varepsilon_{it} \quad (1)$$

where CO_2 is the carbon emission; NRR represents natural resource consumption; URB denotes urbanization; EC indicates energy consumption and GDPPC is GDP per capita; ε_{it} is the error term; i is the individual group index representing the various countries where i is 1,2,3,4,…, N; and t is the time index (that is 2000–2019). All the variables employed in the study are transformed into natural logarithms.

Meanwhile, total natural resource rents may be expected to have different effects on countries' carbon emissions depending on the level of natural resource exploration in the country. Shin et al. (2014b) argued that nonlinearity is endemic within social sciences, and nonlinearity is fundamental to the human condition. Granger and Yoon (2002) further posited that a time series can have hidden cointegration if positive and negative series are cointegrated. In other words, negative total natural resource rent (resource consumption) shocks do not have an equivalent effect with positive total natural resource rent shocks. Hence, we partition total natural resource rent (resource consumption) shock in Eq. (2) into positive and negative total natural resource rents; thus, the revised equation asymmetric form becomes

$$CO2_{it} = \beta_0 + \beta_1 NRR^{+}_{it} + \beta_1 NRR^{-}_{it} + \beta_2 URB_{it} + \beta_3 EC_{it} + \beta_4 EG_{it} + \varepsilon_{it} \quad (2)$$

where NRR^{+} and NRR^{-} denote the positive and negative total natural resource rent (resource consumption) shocks, respectively.

The linear PMG ARDL model

We start our empirical analysis by assuming a linear response of carbon emission to changes in resource consumption (total natural resource rents) and other regressors. Subsequently, we relax this assumption to allow for positive and negative changes in resource consumption (total natural resource rents). Therefore, the symmetric form of the panel ARDL is given as

$$\Delta Y_{it} = \beta_{0i} + \beta_{1i}Y_{1i,t-1} + \beta_{2i}X_{i,t-1} + \sum\nolimits_{j=1}^{N1} Y_{ij}\lambda_{ij}\Delta Y_{i,t-j} + \sum\nolimits_{j=0}^{N2}\gamma_{ij}\Delta X_{t-j} + \mu_i + \varepsilon_{it} \quad (3)$$

$$i = 1,2,3,4,5,6,7\ldots\ldots\ldots\ldots,N; \quad t = 1,2,3,4,5,6,7\ldots\ldots\ldots\ldots.,T$$

where Y_{it} is the natural log of carbon emission for each unit i over a period of time t; X_t represents the log of total natural resource rents at period t; $\mu_i$is the group-specific effect; i is the sampled units, and t is the number of periods. For every cross-section, the long-run slope (elasticity) coefficient is computed as$-\frac{\beta_{2i}}{\beta_{1i}}$ since in the long run, it is assumed that $\Delta Y_{i,\,t-j}=0$ and $\Delta X_{t-j}= 0$. Therefore, the short-run estimate for total natural resource rents is obtained as γ_{ij}. Equation (3) can be re-specified to include an error-correction term as follows:

$$\Delta Y_{it} = \delta_i \upsilon_{i,t-1} + \sum_{j=1}^{N1} \lambda_{ij}\Delta Y_{i,t-j} + \sum_{j=0}^{N2} \gamma_{ij}\Delta X_{t-j} + \mu_i + \varepsilon_{it} \quad (4)$$

where $\upsilon_{i,\,t-1}=Y_{i,\,t-1}$- ϕ_{0i} - $\phi_{1i}\,X_{t-1}$ represents the linear error correction term for every unit; the parameter δ_i is the error-correcting speed of adjustment term for every unit, which is also equivalent to β_{1i}. The parameters ϕ_{0i} and ϕ_{1i} are computed as $-\frac{\beta_{0i}}{\beta_{1i}}$ and $-\frac{\beta_{2i}}{\beta_{1i}}$, respectively. It can be observed that in both Eqs. (3) and (4), there are no decompositions of total natural resource rent (resource consumption) into positive and negative changes; hence, the assumption of linear impact of total natural resource rents on carbon emission under this scenario.

The nonlinear panel ARDL model

Unlike the linear case, this panel ARDL referred to as nonlinear panel ARDL allows for an asymmetric response of total natural resource rents (resource consumption) to carbon emission. Thus, in this case, positive and negative effects are not expected to have identical impacts on carbon emission. Thus, the nonlinear version of Eq. (3) is presented below:

$$\begin{aligned}\Delta Y_{it} &= \beta_{0i} + \beta_{1i}Y_{1i,t-1} + \beta_{2i}^{+}X_{i,t-1}^{+} + \beta_{2i}^{-}X_{i,t-1}^{-} \\ &+ \sum\nolimits_{j=1}^{N1} Y_{ij}\lambda_{ij}\Delta Y_{i,t-j} \\ &+ \sum\nolimits_{j=0}^{N2}\left(\gamma_{ij}^{+}\Delta X_{t-j}^{+} + \gamma_{ij}^{-}\Delta X_{t-j}^{-} + \mu_i + \varepsilon_{it}\right.\end{aligned} \quad (5)$$

Descriptive statistics

Table 1 presents a descriptive analysis of 44 African countries from 2000 to 2019. It shows averages, standard deviations, and minimum and maximum observations. Carbon emission averaged 22.767 MMtonnes against a maximum value of 479.429 MMtonnes. However, urbanization has an average of 8,397,668.000 and a maximum value of 103 million. The GDP per capita, which recorded an average value of 2090.308 (current US$), has a maximum value of 16,213.480.

On the other hand, the total natural resource rent reports an average of 11.258 (% of GDP) and a maximum value equal to 67.918 (% of GDP). The average energy consumption is 0.344 (quad Btu), and the maximum value is 5.728 (quad Btu). Furthermore, the results show that the data are highly skewed and not fairly symmetrical since all the figures reported are greater than 1.

Table 1 Summary descriptive statistics

	CO_2	URB	GDP	NRR	EC
Mean	22.767	8,397,668.000	2090.308	11.258	0.344
Median	2.981	4,010,951.000	984.736	7.446	0.062
Maximum	479.429	103,000,000.000	16,213.480	67.918	5.728
Minimum	0.096	40,917.000	111.927	0.001	0.001
Std. dev.	71.310	12,634,459.000	2670.954	11.657	0.924
Skewness	5.048	3.504	2.456	2.011	4.248
Kurtosis	29.655	19.446	9.581	7.493	21.601
Jarque-Bera	31,785.770	12,504.790	2638.993	1422.853	16,361.530
Probability	0.000	0.000	0.000	0.000	0.000
Observations	940	940	940	940	940

Cross-sectional dependence tests

Before performing the stationarity tests, we first test for the presence of cross-sectional dependence in our panel data. The results of the test are presented in Table 2. The null hypothesis of the test states no cross-sectional dependence. If the *p*-value of the Pesaran's CD statistic is less than the usual significance levels, the null hypothesis is rejected. As shown in the CD statistics and the corresponding *p*-values of the Pesaran's CD test, the null hypothesis of no cross-sectional dependence in the panel and individual variables is rejected at all normal statistical significance levels. Therefore, it implies strong evidence of cross-sectional dependence in the data employed for this study. The issue of cross-sectional dependence is subsequently considered by applying an appropriate panel unit root test.

Panel root tests

Before proceeding to the analysis, we establish the order and verify that all variables chosen in the study are integrated in the same order, a prerequisite of the PMG model. The unit root test results for the panel data of the African countries are reported in Table 3. In econometrics analysis, the stationarity test is pertinent to circumvent the spurious regression trap. Because of the cross-sectional dependence reported in the CSD tests, we apply two second-generation panel unit root tests, which are more efficient than the first-generation panel unit root tests. These tests are the cross-sectional augmented IPS (CIPS) test and the cross-sectionally augmented Dickey-Fuller (CADF) panel unit root estimator developed by Pesaran and Yamagata (2008). The null hypothesis of both tests assumes that all series are non-stationary, while the alternative hypothesis states that some of the series are stationary. Results from the two tests show that all the variables are integrated of order one except urbanization (URB) which is not integrated at the level and first difference in the case of the CIPS test. From the results, we can conclude that all series are mixed-order integrated.

Table 3 Second generation panel unit root tests

Variables	CIPS		CADF	
	I(0)	*I*(1)	*I*(0)	*I*(1)
CO2	− 2.263**	− 4.264***	1.971 (0.052)	2.838 (0.0000)
E.C.	− 2.125**	− 4.105***	2.072 (0.011)	3.249 (0.0000)
GDP	− 2.618***	− 4.110***	2.228 (0.0000)	3.326 (0.0000)
URB	− 1.410	− 1.009	2.959 (0.0000)	2.315 (0.0000)
NRR	− 1.957	− 3.584***	1.97 (0.053)	2.716 (0.0000)

***, **, * denote 1%, 5%, and 10% statistical significance levels, respectively

Results and discussions

We estimate the various equations using the M.G. and PMG estimators and subject the results from the two models to a Hausman test. The Hausman test of long-run homogeneity of coefficients is applied to ascertain which estimator is more appropriate.

We first estimate all the equations with the M.G. and PMG estimators, and then we subject the results from these estimators to the Hausman test. A non-rejection of the null hypothesis implies the adoption of the PMG estimator, while the rejection indicates the adoption of the M.G. estimator. In other words, the PMG estimator is the efficient estimator under the null, while the M.G. estimator is the efficient estimator under the alternative hypothesis. Our Hausman test results substantially support the PMG as the preferred estimator since the *p*-values reported in the linear (see Table 7) and nonlinear (see Table 8) models are greater than 0.05. Therefore, the PMG estimations are the only results discussed in this study.

Panel cointegration tests

We test the null of no cointegration after confirming that all the variables are *I*(1). We first report Pedroni (1999), ADF-based Kao (1999), ADF-based tests, and Johansen Fisher panel cointegration test. The panel cointegration test results presented in Table 4 show that in the Pedroni test, four out of the seven tests suggest the rejection of the no cointegration. It implies the existence of long-run cointegration between

Table 2 Cross-sectional dependence tests

Residual cross-section dependence test (panel)						
Pesaran CD	Statistic	Probability				
	7.759	0.000				
Cross-section dependence test (individual variable)						
Pesaran CD	Variables	CO_2	EC	GDP	NRR	URB
	Statistic	71.345***	91.495***	122.712***	37.853***	142.982***

***, **, * denote 1%, 5%, and 10% statistical significance levels, respectively variables. Also, the Kao and Johansen Fisher panel tests confirm cointegration among the variables (Tables 5 and 6).

The symmetric M.G. and PMG estimation results

The empirical results in Table 7 show that the error-correction coefficient is statistically significant and negative as required and is estimated at − 0.53. It means that approximately 53% of disequilibrium from the past year's shock was eliminated in the current year. The linear PMG estimation from the study reveals that an increase in resource consumption proxied as total natural resource rents of the continent have an insignificant link to carbon emissions in Africa. Thus, a 1% increase in total natural resource rents leads to a 0.004% increase in carbon emission; however, the impact, as reported with a *p*-value of 0.634, is statistically insignificant in the long run. Kwakwa et al. (2020) also found that in Ghana, the extraction of mineral resources leads to increased carbon emissions. Contrary to findings by Danish et al. (2019), when they analyzed the relationship between natural resources and pollution, show that natural resources reduce pollution in Russia.

Table 4 Pedroni residual cointegration test

Alternative hypothesis: common A.R. coefs. (within dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	0.233704	0.4076	− 2.417469	0.9922
Panel rho-statistic	1.108203	0.8661	1.150417	0.8750
Panel PP-statistic	− 6.922722	0.0000	− 7.923427	0.0000
Panel ADF-statistic	− 2.504728	0.0061	− 4.884466	0.0000
Group rho-statistic	3.656118	0.9999		
Group PP-statistic	− 11.13881	0.0000		
Group ADF-statistic	− 3.972175	0.0000		

Table 5 Johansen Fisher panel cointegration test

Hypothesized no. of CE(s)	Fisher stat. (from trace test)	Prob.	Fisher stat. (from max-eigen test)	Prob.
None	1862.	0.0000	1276.	0.0000
At most 1	911.4	0.0000	639.5	0.0000
At most 2	390.9	0.0000	293.1	0.0000
At most 3	194.4	0.0000	153.4	0.0001
At most 4	173.4	0.0000	173.4	0.0000

Table 6 Kao residual cointegration test

	t-statistic	Prob.
ADF	− 4.157257	0.0000

Table 7 Symmetric results of long-run and short-run models

	MG		PMG	
Variables				
Long-run estimates				
NRR	− 0.009	(0.779)	0.004	(0.634)
GDP	− 0.060	(0.410)	− 0.036***	(0.005)
EC	1.036***	(0.000)	1.054***	(0.000)
URB	− 0.086	(0.814)	0.033	(0.387)
Error correction	− 0.879	(0.000)	− 0.538***	(0.000)
NRR	− 0.007	(0.800)	0.021	(0.234)
GDP	0.033	(0.629)	0.047	(0.462)
EC	− 0.023	(0.766)	0.164**	(0.044)
URB	− 12.362	(0.234)	− 2.998	(0.500)
Constant	− 0.564	(0.890)	2.273***	(0.000)
Hausman			0.7	(0.95)

*, **, and *** represent "statistical significance" at 10%, 5%, and 1%, respectively. Also, M.G. denotes the mean group and PMG denotes the pooled mean group

Table 8 Asymmetric results of long-run and short-run models

	MG		PMG	
Variables				
Long-run estimates				
NRR+	0.192*	(0.063)	0.017*	(0.053)
NRR-	0.260*	(0.062)	0.044***	(0.000)
GDP	− 0.095	(0.516)	− 0.038**	(0.002)
EC	0.532*	(0.093)	1.094***	(0.000)
URB	0.287	(0.609)	− 0.048	(0.127)
Error correction	− 0.865***	(0.000)	− 0.495***	(0.000)
NRR+	0.047	(0.223)	0.024	(0.222)
NRR-	− 0.040	(0.273)	− 0.017	(0.368)
GDP	0.041	(0.663)	0.046	(0.509)
EC	0.034	(0.712)	0.195**	(0.022)
URB	− 18.523	(0.067)	− 2.383	(0.573)
Constant	1.488	(0.780)	2.729***	(0.000)
Hausman			1.7	(0.89)

*, **, and *** represent "statistical significance" at 10%, 5%, and 1%, respectively. Also, M.G. denotes the mean group and PMG denotes the pooled mean group

The PMG estimations show that economic development has a statistically significant effect on environmental quality in Africa. A 1% increase in economic development on the continent results in a 0.036% decline in carbon emission in the long run. This means that economic Africa's growth over the two decades is not associated with a surge in carbon emission. This is contrary to what Tamazian et al. (2009) posited that the level of emissions of CO_2 demonstrates the economic growth of every country, implying that the fastest-growing countries have the most significant levels of energy consumption and thus emit the highest levels of CO_2. However, Kumbaroğlu et al. (2008) noted that economic growth contributes to technological advancement, reducing long-run carbon emissions.

Moreover, the study found that a 1% change in energy consumption would lead to an approximately 1.05% increase in carbon emissions in the long run. It can be deduced that energy consumption significantly contributes to Africa's rise in carbon emissions. Our findings are consistent with what Yu-Ke et al. (2021) reported, who found that energy consumption from conventional sources increases carbon emissions in the G-20 countries studied. Africa's growing population and development drive have resulted in high demand for energy, mostly from non-renewable sources, probably accounting for the increase in carbon emission. This phenomenon is not only limited to Africa, as evidence provided in a study conducted by Muhammad (2019) in the Middle East and North African (MENA) countries also confirmed that an increase in energy consumption affected environmental quality adversely.

Furthermore, as reported, no statistically significant relationship exists between urbanization and carbon emissions on the continent in the long run. It implies, therefore, that Africa's rapid growth in urban population increases carbon emissions, although the impact is found to have no significance in the long run. Martínez et al. (2018) concurred that urbanization does play a role in climate change.

The asymmetric M.G. and PMG estimation results

Now, we test the panel data of the 44 African countries by employing the nonlinear pooled mean group (PMG) model, as reported in Table 8. Findings published show that the variables are cointegrated where the error correction coefficient is significant and negative as required. This provides evidence for a long-run relationship between urbanization, economic growth, resource consumption, energy consumption, and carbon emission in Africa.

Regarding the asymmetric relationship between total natural resource rents and carbon emissions, both positive and negative changes in total natural resource rents result in a significant increase in carbon emission, contrary to an insignificant positive relationship reported in the symmetric framework. Our findings reinforce the position of Sarkodie and Adams (2018), who noted that the consumption of natural resources via deforestation, agricultural activities, and mining influences the environment. Most African countries depend mainly on exploring natural resource endowment and agricultural activities to drive the growth of their economies. Due to the weak environmental regulatory frameworks in most African countries and public corruption, multinational companies (MNCs) in the extractive sector do not adhere to environmentally friendly activities. Most African countries also battle illegal mining and illicit felling of trees, which may account for the positive relationship between natural resource rents and environmental quality reported in this study. In a similar study, Yu-Ke et al. (2021) reported mineral resources, oil resources, and forest rent make a significant positive contribution to carbon emissions in G-20 countries.

Furthermore, consistent with our findings, Bekun et al. (2019) also established that natural resource rents contribute to pollution in the E.U. countries. The situation in China is not different, as reported in a study by Ahmed et al. (2020b), which revealed a positive link between natural resources and ecological footprint. It is, however, important to state that Khan et al. (2021) made a divergent discovery in the USA in a study that asserts that natural resources contribute to the improvement of environmental quality consistent with the findings of Balsalobre-Lorente et al. (2018).

The present study observes a significant negative link between increased economic growth and environmental quality in the long run. This is consistent with the negative and statistically significant relationship between growth and carbon emission in the symmetric model reported in Table 7. Economic growth in most African countries and, for that matter, the continent is majorly driven by the agricultural sector. The industrial sector, which requires a high demand for energy consumption, does not play a significant role in economic growth in most countries as they continue to depend on exporting raw materials. Activities in the agricultural sector, which is the backbone of economic growth, possibly accounted for the negative link established between economic growth and environmental quality in our study. Contrary to our findings, Wang et al. (2020), in a study, found that economic growth contributes to carbon emissions in China. Chebbi et al. (2011) also agree that economic development adversely affects pollution levels.

In the nonlinear framework, the study also established that a rise in urban population is negatively associated with carbon emission; however, the association is not statistically significant. The linear estimates also show similar results, although with a slightly lower coefficient value. In the case of Indonesia, Ahmed et al. (2019) made contrary findings that established a positive relationship between urbanization and carbon emission. Furthermore, Li et al. (2019a) and Azizalrahman (2019) also confirmed that urbanization increases carbon emissions in China and high-income countries, respectively.

Regarding energy consumption, the nonlinear estimates are similar to the linear ones, confirming a significant positive link between energy consumption and environmental quality in Africa. The results show that a 1% increase in energy consumption, in the long run, has a positive and statistically significant effect of 1.094% on carbon emissions. These findings further reinforce energy's considerable contribution to environmental quality in Africa. The gradual growth in the manufacturing sector and an expansion in the transportation sector in Africa led to high demand and consumption of fossil fuels. This possibly accounts for the adverse effect energy consumption is reported to have on carbon emissions in this study. Bhat (2018) found similar results, which revealed that non-renewable energy consumption increases CO_2 emissions, consistent with the findings of Destek and Sinha (2020) in the Organization of Economic Co-operation and Development (OECD) countries.

In the short run, no significant relationship existed between positive and negative shocks in natural resource consumption, urbanization, economic growth, and carbon emission. Energy consumption, however, has a significant adverse effect on environmental quality.

Conclusion

This paper investigated the impact of natural resource consumption on environmental quality in Africa. Total natural resource rents and carbon emissions were used as resource consumption and environmental quality proxies, respectively. The linear and nonlinear ARDL panel cointegration approach was employed for a panel of 44 African countries from 2000 to 2019. The linear estimations show that total natural resource rents increase carbon emissions; however, the impact is insignificant in the long and short runs. Meanwhile, consistent with most previous studies, energy consumption was found to significantly increase carbon emissions in the long and short runs. Interestingly, growth was reported to decrease carbon emissions in the long run, but no significant relationship was found in the short run. On the other hand, findings from the nonlinear estimations show that a positive and negative shock to total natural resource rents in the sample analyzed increases carbon emission and is significant in the long run but not statistically significant in the short run.

From the policy perspective, therefore, it can be concluded that total natural resource rents, irrespective of an increase or decline, adversely impact environmental quality in Africa. It means mineral-rich countries in Africa must encourage the preservation of natural resources. Governments of Sub-Saharan African countries must enact and implement environmental sustainability laws that prevent using illegal and unorthodox methods in the resource extraction sector. Multinational companies in the extractive sector must engage in eco-friendly activities and strictly adhere to environmental regulations that aim to protect the environment. African governments must also explore other revenue-generation sources and reduce the over-dependence on natural resources. It is also essential for governments of resource-rich African countries to use revenue generated from natural resource explorations judiciously to offset the accompanied carbon emissions due to the resource extraction activities.

Energy consumption continues to significantly contribute to environmental degradation in Africa. Rapid urbanization on the continent does not significantly impact ecological quality on the continent. Therefore, we recommend policies that aim to reduce the amount of greenhouse gases in the atmosphere to alleviate the increase in planet overall temperature and resulting impacts. We entreat policymakers in African countries to explore renewable energy sources by adequately importing advanced technologies for renewable energy production. Governments must endeavor to take deliberate policy actions such as withdrawing subsidies on fossil fuels and applying such subsidies on renewable energy sources, bringing down the cost and making renewable consumption affordable. Proper education on the consequences of environmental degradation will go a long way to enable citizens to adopt environmentally friendly lifestyles to improve environmental quality. Corporate organizations should be encouraged to channel their corporate social responsibility activities into ecological innovation. Tax incentive packages in the form of tax waivers should be offered to companies that invest in eco-friendly production activities that contribute to reducing carbon emissions.

Authors' contribution Befeke Larry Chenyi and Bosah Philip Chukwunonso conceived of the presented idea. All authors developed the theory and performed the computations and design. Befeke Larry Chenyi, Bosah Philip Chukwunonso, and Shaw Williams performed material preparation, data collection, and analysis. Huang Delin supervised the findings of this work. All authors read and approved the final manuscript.

Data availability The data that support the findings of this study are openly available in World Bank Development Indicators (WDI) database, US Energy Information Administration (EIA), as well as in this article.

Declarations

Ethical approval This research did not contain any studies involving animal or human participants, nor did it occur in private or protected areas. No specific permissions were required for corresponding locations.

Consent to participate All authors of this paper have directly participated in the planning, execution, and analysis of this study and approved the final version.

Consent for publication All authors have approved the manuscript and agree with its submission to *Environmental Science and Pollution Research*.

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