Contents list available at CBIORE journal website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.cbiore.id

Research Article

Unveiling the Nexus: Analyzing foreign direct investment and energy consumption in shaping carbon footprints across Africa's leading CO_2-emitting countries

Yahya Njie *, Weidong Wang, Lin Liu, Abdullah

School of Finance and Economics, Jiangsu University, Zhenjiang 212013, Jiangsu, P.R. China

Abstract. Carbon emissions have become a pressing global concern because of its contribution to climate change and environmental degradation. Given the urgency to tackle climate change, especially by reducing carbon emissions, this study focuses on Africa's leading CO_2 emitters from 2000 to 2020. The aims of the study are; to examine whether there is evidence of an energy-Kuznets Curve among the leading CO_2 emitters in Africa, to examine whether there is evidence of an FDI-Kuznets Curve among the leading CO_2 emitters in Africa, and to Identify the turning points. The study employs an innovative analysis of unbalanced panel data utilizing sophisticated econometric techniques, the contemporaneous correlation methodology, which are; the feasible generalized least squares (FGLS), and the panel-corrected standard errors (PCSE) to uncover insights. The results reveal consistency across all employed techniques. The study confirms the existence of an Energy-Kuznets Curve among the leading CO_2 emitters in Africa; it also finds evidence of a U-shaped relationship between foreign direct investment and carbon emissions among the leading CO_2 emitters in Africa; finally, it also identifies crucial turning points at 2760.12kg and 2886.29kg of oil equivalent per capita for energy use and 6.89% and 6.17% for FDI inflow, respectively. By investigating the factors influencing carbon emissions and evaluating their impacts, our study offers valuable insights for policymakers. These findings can inform the development of targeted interventions to curb emissions intensity, enhance energy efficiency, and foster the adoption of renewable energy sources.

Keywords: Foreign Direct Investment, Energy Consumption, CO_2 Emission, Africa's Leading CO_2 Emitting Countries

Received: 16th May 2024; Revised: 27th June 2024; Accepted: 25th July 2024; Available online: 5th August 2024

1. Introduction

The global community has acknowledged the urgent need to address climate change more and more in recent decades, focusing on reducing carbon emissions (Filho *et al.*, 2023; Adeleye *et al.*, 2023). The Sustainable Development Goal (SDG) of the United Nations for 2030 Agenda 13 demands immediate action to mitigate the effects of climate change. It relates to the other Sustainable Development Goals of the 2030 Agenda. Countries ratified the Paris Agreement to combat climate change, pledging to keep increases in global temperatures well below 2^0C and to work toward limiting them even further to 1.5^0C(Blau, 2017; Teske, 2019; Abbass *et al.*, 2022). Despite Africa being historically responsible for a relatively small portion of global carbon dioxide (CO_2) emissions levels (Erdoğan *et al.*, 2022), it has seen a notable increase in its contribution to atmospheric CO_2 (Mensah *et al.*, 2021). This phenomenon is primarily attributed to rapid industrialization, urbanization, and economic growth in several African countries (Sikder *et al.*, 2022; Appiah & Korankye, 2021). Thus, it is crucial to comprehend the causes of climate change, including CO_2 emissions to address it.

The declaration of COVID-19 as a pandemic profoundly impacted global health. Governments worldwide implemented strict measures to control the virus's spread, including the first lockdown (Yassine & Sebos, 2024). These measures caused significant disruptions to the global economy and inadvertently led to a temporary reduction in CO_2 emissions (Papadogiannaki *et al.*, 2023).

Energy consumption is fundamental to economic development and human well-being (Jorgenson *et al.*, 2014; Esseghir & Khouni, 2014). In Africa, energy demand has surged alongside economic growth, driven by expanding industries, urbanization, and rising living standards. However, the majority of energy production in Africa relies heavily on non-renewable resources such as fossil fuels, biomass, animal waste, etc. (Kebede *et al.*, 2010), Which are associated with high CO_2 emissions. Balancing the imperative for increased energy access with the need to mitigate CO_2 emissions poses a significant challenge for policymakers across the continent. Through programs like Agenda 3, 7, and 13 of the Sustainable Development Goal 2030, inexpensive, sustainable energy, human health and well-being, and climate action are encouraged. However, developing countries often emphasize their right to pursue economic development and poverty alleviation, highlighting the need for adequate resources, technology transfer, and capacity-building assistance to achieve sustainable development goals without compromising

* Corresponding author
Email: yahya.njie@edugambia.gm (Y. Njie)

environmental integrity. For every 1% increase in social inequality, mitigation and adaptation efforts in African countries decrease by almost 23% (Nyiwul, 2021).

Climate change is humanity's paramount challenge today, poised to escalate in severity over the next few decades. As global temperature rises, it disrupts weather patterns, upsetting the delicate balance of ecosystems (Ioanna *et al.,* 2022). These impacts are increasingly severe and damaging, affecting all sectors of the economy (Kyriakopoulos *et al*., 2023). Despite efforts to bolster renewable energy sources through policy, their implementation remains costly and intricate, limiting widespread adoption (Sebos *et al*., 2016). Climate change disproportionately affects African countries, exacerbating vulnerabilities such as food insecurity, water scarcity, and extreme weather events (Byaro *et al*., 2022). CO_2 emissions predominantly from burning fossil fuels in various sectors, such as power generation, transportation, residential, and industrial activities, are a significant driver of global warming and climate disruption (Ritchie *et al*., 2020; Adeleye *et al.,* 2023). The broad consensus among scientists is that more greenhouse gas concentrations like CO_2 trap heat in the atmosphere of the earth causing temperature increases, ice caps to melt, sea levels to rise, and extreme weather phenomena.

Foreign direct investment (FDI) is a significant factor in determining how African countries' economies are structured. It often facilitates technology transfer, infrastructure development, and job creation, all of which contribute to economic growth (Odhiambo, 2022; Ciftci & Durusu-Ciftci, 2022). However, the extent to which FDI impacts CO_2 emissions remains inconclusive. Some studies argue that FDI leads to adoption of cleaner technologies and practices, reducing emissions intensity (Adams *et al*., 2020; Asongu & Odhiambo, 2021; Bakhsh *et al*., 2021). Conversely, others contend that FDI may exacerbate environmental degradation through increased industrial activity and energy consumption (Abdouli & Hammami, 2017). As Africa continues to attract increasing amounts of FDI, particularly in sectors such as extractive industries, manufacturing, and infrastructure development, the environmental implications of these investments merit careful consideration. Without adequate safeguards and regulations, FDI may inadvertently contribute to environmental degradation and exacerbate CO_2 emissions in host countries.

Given this background, our research seeks to add to the empirical literature on the impact of FDI and energy use on CO_2 emission levels, with a particular emphasis on the leading CO_2 emitting countries in Africa. To achieve this, we examine unbalanced panel data that includes carbon emissions per capita, energy use in kilograms of oil equivalent, foreign direct investment net inflow, and a range of control variables: GDP per capita, Population growth, Renewable energy consumption, and Regulatory Quality, spanning from 2000 to 2020. The aims of our study are: (1) to examine whether there is evidence of an Energy-Kuznets Curve among the leading CO_2 emitters in Africa. (2) to examine whether there is evidence of an FDI-Kuznets Curve among the leading CO_2 emitters in Africa. (3) Identify the turning points. To address these objectives comprehensively, we employed two estimation techniques to ensure our findings' robustness: feasible generalized least squares (FGLS) and panel-corrected standard errors (PCSE). Our study distinguishes itself from prior studies by employing FGLS and PCSE analyses. Our study marks a pioneering effort in applying such a methodological approach within the unique African context, particularly in examining the leading CO_2 emitters in Africa. To the best of our knowledge, no study has investigated the FDI-Kuznets Curve among the leading CO_2 emitters in Africa. Our analysis reveals consistent results across all employed techniques. The study confirms the existence of an Energy-Kuznets Curve among the leading CO_2 emitters in Africa; additionally, it also finds evidence of a U-shaped relationship between FDI and CO_2 emissions among the leading CO_2 emitters in Africa and identifies crucial turning points at 2760.12kg and 2886.29kg of oil equivalent per capita for energy use and 6.89% and 6.17% for FDI inflow, respectively. By investigating the factors influencing carbon emissions and evaluating their impacts, our study offers valuable insights for policymakers. These findings can inform policymakers in developing targeted interventions to curb emissions intensity, enhance energy efficiency, and foster the adoption of renewable energy sources. The remaining section of our study is structured as follows: the theoretical framework and literature review section provides an overview of relevant theories and existing literature; the methodology section outlines the empirical and analytical techniques utilized; the results and discussions section explains our findings and provides interpretations and insights. Lastly, the conclusion and policy recommendations section summarize our findings and proposes policy recommendations for implementation.

2. Theoretical framework and Literature review

2.1 Theoretical framework

Carbon emissions are a critical environmental issue, particularly in developing regions like Africa where rapid industrialization and economic growth often coincide with increased pollution (Destek & Sinha, 2020; Appiah *et al*., 2021; Erdoğan *et al*., 2022). This theoretical framework reviews the relationship between FDI, energy use, and CO_2. Drawing on *environmental Kuznets' Curve (EKC) hypotheses, the pollution haven hypothesis (PHH), and the halo effect hypothesis (HEH),*

The environmental kuznets curve (EKC) is a notable analytical tool for assessing environmental performance, originating from the work of Simon Kuznets (1955), the EKC portrays an inverted U-shaped curve initially devised to explore the association between income per capita and income inequality. Its significance rose as researchers began applying the inverted U-shape pattern to environmental investigations. Consequently, the EKC has gained popularity and widespread application as a theoretical framework for examining the relationship between economic growth and environmental degradation (Shahbaz *et al*., 2019; Hamid *et al*., 2021; Alsaedi *et al*., 2022; Erdoğan *et al*., 2022; Adeleye *et al*., 2023). Initially, as economies grow environmental degradation worsens. However, further economic growth leads to environmental improvement beyond a certain income threshold. This theory suggests that as African countries experience economic growth facilitated by FDI and increased energy consumption, carbon emissions may initially rise before eventually declining.

An economic theory known as the pollution haven hypothesis (PHH) contends that in an effort to reduce production costs, firms often relocate from countries with strict environmental restrictions to others with less stringent laws resulting in increased pollution in those countries. In Africa, where regulatory enforcement may be weaker than in developed countries, FDI influx could increase pollution levels (Abdouli & Hammami, 2017). On the contrary, the halo effect hypothesis (HEH) proposes that FDI brings not only capital but also technology, managerial expertise, and best practices, which could lead to environmental improvements. FDI may facilitate the adoption of cleaner technologies and sustainable practices, thereby reducing carbon emissions. The relationship between FDI, energy use, and CO_2 is complex and multifaceted. The EKC suggests a non-linear relationship between economic development and environmental degradation, the PHH suggests a positive association, and the HEH suggests a negative association between FDI inflows and CO_2 emissions in African countries. Therefore, empirical analysis is essential to understand the relative importance of these factors and their implications for environmental policy and sustainable development in Africa.

2.2. Energy Consumption and Carbon Emissions

Carbon emissions have become a pressing global concern because of their contribution to climate change and environmental degradation (Erdoğan *et al*., 2022). Despite Africa being a relatively minor contributor to global CO_2 emissions, it faces increasing pressure to mitigate its carbon footprint, especially as it strives for economic development.

The intricate relationship between energy consumption and carbon emissions is central to understanding environmental challenges, particularly in African countries where fossil fuels remain a dominant energy source amid rapid industrialization and urbanization. This reliance on fossil fuels has increased CO_2 emissions exacerbating environmental concerns (Erdoğan *et al*.,.2022). However, the dynamics between energy consumption and carbon emissions are multifaceted.

Research conducted by Adams *et al.* (2020), Appiah and Korankye (2021), and Adeleye *et al.* (2023) highlights the significant impact of factors such as energy use, renewable energy consumption, and policy interventions on CO_2 emissions. In a study focused on Sub-Saharan Africa (SSA), Ssali *et al.* (2019) explored the intricate relationships among CO_2 emissions, economic growth, and foreign direct investment (FDI). Their findings revealed that GDP growth and energy consumption were linked to a decline in environmental quality, indicating a bidirectional causality between energy use and CO_2 emissions in the short term. However, only energy use significantly influenced CO_2 emissions in the long run, underscoring a complex interaction between economic activities and environmental outcomes. Similarly, Alsaedi *et al.* (2022) examined the relationship between CO_2 emissions and economic growth, finding an inverted U-shaped curve that aligns with the environmental Kuznets curve hypothesis. Their research suggested that a 1% increase in energy consumption leads to a 0.592% rise in CO_2 emissions when GDP remains constant, while a 1% increase in GDP results in a 0.282% increase in CO_2 emissions when energy consumption is held steady. These findings collectively underscore the nuanced and multifaceted dynamics between economic development and environmental sustainability.

Sikder *et al.* (2022) conducted an in-depth analysis on the impacts of energy usage, industrialization, GDP growth, and urbanization on CO_2 emissions across 23 developing countries from 1995 to 2018. Using the Panel Autoregressive Distributed Lag (ARDL) approach and the heterogeneous causality test, they found that a 1% increase in energy use, GDP growth, industrialization, and urbanization leads to long-term increases in CO_2 emissions of 0.23%, 0.17%, 0.54%, and 2.32%, respectively. These results highlight that in developing countries CO_2 emissions are significantly driven by GDP growth, energy use, industrialization, and urbanization. In a related study, Belaïd and Zrelli (2019) demonstrated that non-renewable electricity consumption and economic growth drive CO_2 emissions in southern and northern Mediterranean countries, whereas renewable electricity consumption reduces emissions. Similarly, Shahbaz *et al.* (2019) confirmed the environmental Kuznets curve (EKC) hypothesis in the Middle East and North Africa, showing a relationship between economic growth and carbon emissions. Mensah *et al.* (2021) revealed that economic growth and fossil fuel energy use contribute to environmental degradation. This finding is supported by Erdoğan *et al.* (2022), who found a negative effects of fossil energy consumption and urbanization on environmental quality in African countries reinforcing the EKC hypothesis. These studies underscore the complex interactions between economic activities and environmental outcomes, particularly in developing countries.

Further insights from Murshed *et al.* (2022) revealed that enhancing the use of renewable electricity and fostering technological innovation significantly reduce CO_2 emissions. However, they found that trade globalization tends to increase CO_2 emissions. Their findings also validated the EKC hypothesis for CO_2 emissions. Nguyen and Kakinaka (2019) used panel cointegration techniques to analyze data from 107 countries between 1990 and 2013, finding that renewable energy consumption is positively and negatively associated with CO_2 emissions and economic output, respectively. Interestingly, in high-income countries, renewable energy consumption showed a negative association with CO_2 emissions and a positive association with output. Conversely, studies by Pata and Aydin (2020) and Pata and Caglar (2021) failed to confirm the validity of the EKC hypothesis in certain contexts, suggesting a more complex relationship between economic growth and environmental degradation. Similarly, Destek and Sinha (2020) examined the EKC hypothesis regarding ecological footprint across 24 OECD countries from 1980 to 2014 using the Panel Mean Group (PMG) estimator. They found that renewable energy consumption reduces environmental impact, while non-renewable energy consumption increases it, ultimately challenging the inverted U-shaped EKC hypothesis. Appiah *et al.* (2021) focused on Sub-Saharan Africa (SSA) countries. They found that industrialization, urbanization, and fossil fuel consumption have a non-significant positive impact on CO_2 emissions, whereas energy use has a significant impact. These studies collectively underscore the intricate connections between energy use, economic growth, and environmental effects. They highlight the necessity of specialized policies to mitigate carbon emissions and promote sustainable development, emphasizing these relationships nuanced and context-specific nature.

Yassine and Sebos, (2024) provide essential background statistics and information on the greenhouse gas (GHG) emissions in Oman's fisheries sector from 2015 to 2020. They found approximately 1529.50 kt CO_2-eq by 2020 and an average Carbon Emission Intensity of 1.95 kg CO_2-eq per kilogram of landed fish. Martín- Ortega *et al.* (2024) assess alternative mitigation pathways for Tajikistan to achieve carbon neutrality by 2050, employing a novel five-step back-casting approach. The study identifies four different mitigation pathways for Tajikistan, each with varying levels of policy intensity across different sectors. However, only one reaches carbon neutrality by 2050, namely, the pathway that focuses on considerable policy efforts in all sectors of the economy and incorporates intensive policy efforts for both nature-based and technological CO_2 removal.

2.3. Foreign Direct Investment and Carbon Emissions

The economic environment of African countries is significantly shaped by FDI (Duodu *et al*., 2021). While FDI is often associated with economic growth and development, its environmental implications particularly concerning CO_2 emissions have garnered attention. Existing literature suggests a mixed relationship between FDI and CO_2 emissions.

In-depth investigations by Ojewumi and Akinlo (2017) utilized panel vector error correction and autoregressive methods to explore the dynamic interplay among FDI, economic growth, and environmental quality in Sub-Saharan Africa (SSA). Their findings underscore significant interactions among these variables, indicating that alterations in one variable could exert considerable influence on others, with effects ranging from 13.1% to 32.8%. (Duodu *et al.*, 2021) examined the relationship between FDI and environmental quality in 23 sub-Saharan African (SSA) countries by using the Generalized Method of Moment (System-GMM) to evaluate data from 2005 to 2019. The findings showed that while FDI can enhance environmental quality over an extended period, it can also have an opposite effect in the short term when interact with institutions and policies promoting environmental sustainability. Similarly, Adams *et al.* (2020) emphasize the pivotal role of regulatory quality and FDI in mitigating carbon emissions in SSA countries, emphasizing the significance of policy interventions and FDI in addressing environmental degradation. Shahbaz *et al.* (2019) found an inverted-U relationship between FDI and carbon emissions in the Middle East and North Africa, suggesting the presence of EKC hypotheses.

Similarly, Hamid *et al.* (2021) conducted a similar longitudinal study spanning from 1980 to 2019, revealing that positive shocks to FDI inflows, economic growth, and capital investments led to increased CO_2 emissions in both the short and long term, while negative shocks resulted in emissions reduction, affirming the EKC hypotheses and pollution haven hypotheses (PHH). (Djellouli *et al.*, 2022) investigated foreign direct investment in environmental degradation in twenty selected African countries over the period 2000 to 2015, no evidence supporting the EKC hypothesis was discovered, but strong evidence for the PHH was found in specific African countries.

However, other studies highlight the negative environmental consequences of FDI, such as increased industrial activity and energy consumption which could escalate CO_2 emissions. These contrary perspectives are evident in studies such as; Abdouli and Hammami (2017), who scrutinized the causal relationships among environmental quality, FDI, and economic growth in 17 Middle Eastern and North African countries. Utilizing the Equation Panel Vector Autoregressive model, they discovered a significant positive impact of FDI on CO_2 emissions across all countries. They identified a bidirectional relationship between FDI, economic growth, and CO_2 emissions. Salahuddin *et al.* (2020) found that FDI has a detrimental impact on the environment in SSA, as evidenced by its statistically significant positive coefficient on CO_2 emissions. Similarly, Asongu and Odhiambo (2021) delved into trade and FDI thresholds for CO_2 emissions in SSA countries, revealing that while enhancing trade openness yielded a net positive impact on CO_2 emissions, increased FDI had a net negative effect. Moreover, they found a U-shaped relationship between CO_2 emissions and FDI inflows. This disparity underscores the ongoing discourse surrounding the environmental implications of FDI and the necessity for tailored policy responses.

3. Methodology

3.1 Data Description and Source

This research utilized an unbalanced annual panel dataset from Africa's ten leading CO_2 emitters from 2000 to 2020. The focal point of analysis is CO_2 emissions (metric tons per capita). The core explanatory variables are foreign direct investment net inflow (% GDP) and energy use (kg of oil equivalent per capita). The following control variables are used for understanding the factors influencing carbon emissions in the study: GDP per capita (constant 2010 US$), Population growth (annual %), Regulatory Quality, and Renewable energy consumption (% of total final energy consumption), which are presented in Table 1.

The study has the following underlying hypothesis: $H_0\colon \varphi_1 > 0$, posits that energy use has a positive significant influence on CO_2 emission (Belaïd & Zrelli, 2019; Ssali *et al.*, 2019; Alsaedi *et al.*, 2022; Mensah *et al.*, 2021; Sikder *et al.*, 2022), and $H_0\colon þ < 0$, posits that FDI has a negative significant influence on CO_2 emission (Adams *et al.*, 2020; Asongu & Odhiambo, 2021; Duodu *et al.*, 2021).

3.2 Model specification

By our study objectives, we established a baseline model wherein carbon emissions are represented as a linear function of several control variables: GDP per capita, population growth, regulatory quality, and energy use:

$$lnCO_{2it} = \beta_0 + \beta_1 lnPC_{it} + \beta_2 PGR_{it} + \beta_3 REQ_{it} + \beta_4 REN_{it} + \varepsilon_{it} \quad (1)$$

To address the first objective of examining whether there is evidence of an energy use-Kuznets Curve among the leading CO_2 emitters in Africa, we incorporated both the level and square of energy use into Equation (1).

$$lnCO_{2it} = \beta_0 + \beta_1 lnPC_{it} + \beta_2 PGR_{it} + \beta_3 REQ_{it} + \beta_4 REN_{it} + \varphi_1 EN_{it} + \varphi_2 ENSQ + \nu_{it} \quad (2)$$

To address the second objective of examining whether there is evidence of an FDI inflow-Kuznets Curve among the leading CO_2 emitters in Africa, we incorporated both the level and square of FDI into Equation (1).

$$lnCO_{2it} = \beta_0 + \beta_1 lnPC_{it} + \beta_2 PGR_{it} + \beta_3 REQ_{it} + \beta_4 REN_{it} + þ_1 FDI_{it} + þ_2 FDISQ_{it} + \vartheta_{it} \quad (3)$$

To ascertain if the energy use-Kuznets and FDI-Kuznets hypotheses hold despite the inclusion of all the variables under evaluation Eq. (2) and (3), we incorporated both into Eq. (1) to become Eq.(4).

$$lnCO_{2it} = \beta_0 + \beta_1 lnPC_{it} + \beta_2 PGR_{it} + \beta_3 REQ_{it} + \beta_4 REN_{it} + \varphi_1 EN_{it} + \varphi_2 ENSQ_{it} + þ_1 FDI_{it} + þ_2 FDISQ_{it} + ŋ_{it} \quad (4)$$

Where: $lnCO_2$ is the natural logarithms of CO_2 emissions (metric tons per capita), lnPC is the natural logarithms of GDP per capita (constant 2010 US$), PGR is Population growth (annual %),

Table 1
Variables, Description, and Expected Signs

Variable	Description	Signs	Source
$lnCO_2$	CO_2 emissions (metric tons per capita)	N/A	World Bank (2022)
lnPC	GDP per capita (constant 2010 US$)	+	World Bank (2022)
FDI	Foreign direct investment, net inflows (% of GDP)	-	World Bank (2022)
PGR	Population growth (annual %)	+	World Bank (2022)
REN	Renewable energy consumption (% of total final energy consumption)	-	World Bank (2022)
REQ	Regulatory Quality: Percentile Rank, Upper Bound of 90% Confidence Interval	-	World Bank (2022)
ENU	Energy use (kg of oil equivalent per capita)	+	World Bank (2022)

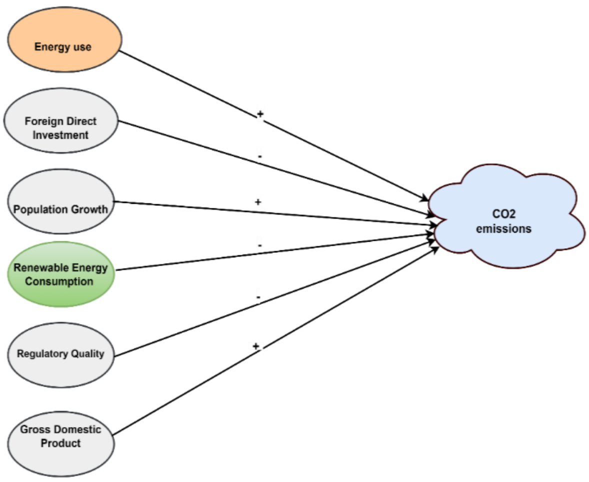

Fig 1. Research model

Table 2

Quadratic model coefficient interpretation, Eq (2) & Eq (3)

Coefficients	Interpretation
φ₁, þ₁ < 0, **φ**₂, þ₂ >0	reveals a U-shaped relationship
φ₁, þ₁ > 0, **φ**₂, þ₂ <0	reveals an inverse U-shaped relationship
φ₁, þ₁ > 0, **φ**₂, þ₂ >0	reveals a monotonically increasing linear relationship
φ₁, þ₁ < 0, **φ**₂, þ₂ <0	reveals a monotonically decreasing linear relationship
φ₁, þ₁ = 0, **φ**₂, þ₂ =0	reveals a level relationship.

Note: φ_1 coefficient of (EN) energy use; φ_2 coefficient of (ENSQ) Square of energy use; $þ_1$ coefficient of (FDI) foreign direct investment; $þ_2$ coefficient of (FDISQ) square foreign direct investment

Source: Authors' computations

REQ: is the log of Regulatory Quality: Percentile Rank, Upper Bound of 90% Confidence Interval, REN is Renewable energy consumption (% of total final energy consumption), EN is energy use (kg of oil equivalent per capita), ENSQ is the square of energy use (kg of oil equivalent per capita), FDI is Foreign direct investment, net inflows (% of GDP), FDISQ is the square of Foreign direct investment, $\beta_1, \beta_2, \beta_3, \beta_4, \varphi_1, \varphi_2, þ_1$ *and* $þ_2$ are coefficients to be estimated, $\varepsilon_{it}, v_{it}, \vartheta_{it},$ *and* $ŋ_{it}$ are the error term. Figure 1 illustrates our research model along with the anticipated signs.

To address the third objective, Identifying the turning points, we employed Equations (2) and (3) to examine the various (linear and quadratic) relationships between forms of energy use and FDI with CO_2 emissions. To determine the turning point for energy use, we calculated the derivative of Equation (2) concerning energy use as:

$$\frac{dlnCO_2}{dENU} = \varphi_1 + (2 * \varphi_2)EN \quad \xrightarrow{yields} \quad EN^* - 0.5\frac{\widehat{\varphi}_1}{\widehat{\varphi}_2} \quad (5)$$

Similarly, for the FDI turning point, we calculate the derivative of Equation (3) as:

$$\frac{dlnCO_2}{dFDI} = þ_1 + (2 * þ_2)FDI \quad \xrightarrow{yields} \quad FDI^* - 0.5\frac{\hat{þ}_1}{\hat{þ}_2} \quad (6)$$

For the energy use -Kuznets hypothesis and FDI-Kuznets hypothesis to hold, we anticipate the following coefficients: **φ**1, þ1 > 0, and **φ**2, þ2 <0. Table 2 provides a clear interpretation of these relationships.

3.3 Data analysis

We commenced our empirical analysis with the application of the cross-sectional dependence (CSD) test among the countries to determine the suitable methods to apply. Using the (Pesaran, 2004) CD test which can be applied to small and large panels to detect the presence of CD and guide the selection of appropriate modelling techniques to mitigate its effects. The CSD test is crucial to panel data analysis's ability to assure the validity and dependability of empirical findings. CSD can induce spurious regression results, where unrelated variables appear statistically significant due to correlation among the error terms (Pesaran, 2004). The null hypothesis of the CSD test "no cross-sectional dependency" can be rejected at the 1%, 5%, and 10% significance levels. CSD equation is expressed as;

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=1+1}^{N}\hat{\rho}_{ij}\right) \quad (7)$$

With CSD, we performed second-generation unit root tests to handle CSD present in panel data. In this study, the Pesaran test (Pesaran, 2007) is utilized among the second generation of unit root tests, which are grounded on the assumption of CSD; we also used (Harris & Tzavalis, 1999) unit root test, a first generational test as a preliminary check. A fundamental distinction between the two generations of tests lies in the assumption regarding CSD. The first-generation tests assume independence across all cross-sections, whereas the second-generation tests depart from this assumption. The latter is particularly valuable in scenarios where CSD is evident in countries' economic activity within the same economic sphere (Pesaran, 2007). The Pesaran test augments Dickey-Fuller (ADF) regressions by incorporating the cross-sectional average of lagged levels and the first differences of individual time series. This approach employs cross-sectionally augmented ADF statistics (CADF), which can be computed as follows:

$$\Delta y_{it} = \beta_i + \Theta_i y_{i,t-1} + \Phi_i \bar{y}_{t-1} + \alpha_i \Delta\bar{y}_i + \varepsilon_{i,t} \quad (8)$$

Where $\beta_i, \Theta i, \Phi_i$ *and* α_i, denote slope coefficients estimated from the ADF test in country I; $\bar{y}_{t-1}$ represents the mean value of lagged levels, and $\Delta\bar{y}_i$ is the mean value of first-differences; $\varepsilon_{i,t}$ is the error term.

Pesaran (2007) suggested modified IPS statistics based on the average of individual CADF, denoted as a cross-sectionally augmented IPS (CIPS), which can be estimated from:

$$CIPS = N^{-1}\sum_{i=1}^{N} t_i(N,T) \quad (9)$$

Where; $t_i(N,T)$ is the t-statistic of the OLS estimate in Equation (8).

We also assessed if a long-run relationship exists among the variables using the second-generation panel cointegration tests proposed by Westerlund (2007). This method is appropriate when CSD is present in the data, and the null hypothesis of "no cointegration" can be rejected with statistical significance levels of 1%, 5%, and 10%. Finally, given the presence of cross-sectional dependence in the data and cointegration among the variables, we applied contemporaneous correlation

Table 3
Summary Statistics and Pairwise Correlation Analysis

	Variable	$lnCO_2$	lnPC	FDI	PGR	REN	REQ	EN
Full Sample	Observation	210	210	210	210	210	200	150
	Mean	0.501	25.378	2.368	1.976	30.830	40.095	1076.238
	Std. Dev.	1.065	0.835	3.389	1.052	29.954	21.678	899.539
	Minimum	-1.531	23.722	-10.038	-5.280	0.060	2.381	257.781
	Maximum	2.301	26.957	24.009	3.759	88.680	81.081	3243.823
Algeria	Observation	20	20	20	20	20	19	15
	Mean	1.175	25.647	1.095	1.708	0.287	31.502	1066.623
	Std. Dev.	0.158	0.192	0.560	0.261	0.162	14.887	141.593
	Minimum	0.925	25.294	-0.324	1.349	0.060	11.905	866.947
	Maximum	1.385	25.902	2.033	2.000	0.580	51.471	1333.136
Angola	Observation	21	21	21	21	21	20	15
	Mean	-0.107	24.873	2.242	3.547	57.775	25.277	486.473
	Std. Dev.	0.146	0.366	8.970	0.168	8.335	6.356	40.183
	Minimum	-0.523	24.167	-10.038	3.244	47.840	15.217	433.186
	Maximum	0.118	25.229	24.009	3.759	73.440	36.190	550.601
Egypt	Observation	21	21	21	21	21	20	15
	Mean	0.746	26.330	2.841	2.048	6.120	46.212	762.315
	Std. Dev.	0.124	0.262	2.621	0.157	1.021	9.129	102.852
	Minimum	0.474	25.915	-0.205	1.733	4.930	29.524	568.684
	Maximum	0.876	26.745	9.349	2.344	8.260	58.152	864.942
Ghana	Observation	21	21	21	21	21	20	15
	Mean	-0.931	24.305	4.956	2.465	53.291	58.216	291.132
	Std. Dev.	0.275	0.387	2.696	0.204	9.571	4.262	24.311
	Minimum	-1.380	23.722	0.956	2.066	40.250	50.270	257.781
	Maximum	-0.506	24.863	9.466	2.748	71.620	65.761	325.247
Libya	Observation	21	21	21	21	21	20	15
	Mean	2.140	24.863	1.270	1.306	2.757	10.354	2987.446
	Std. Dev.	0.103	0.222	1.856	2.148	0.294	7.069	253.019
	Minimum	1.900	24.453	-0.390	-5.280	2.040	2.381	2211.807
	Maximum	2.301	25.153	6.892	2.610	3.160	23.301	3243.823
Morocco	Observation	21	21	21	21	21	20	15
	Mean	0.442	25.205	2.455	1.257	13.910	58.623	487.276
	Std. Dev.	0.146	0.245	1.241	0.089	3.433	3.289	62.308
	Minimum	0.141	24.751	0.992	1.044	10.450	50.490	385.890
	Maximum	0.671	25.541	6.444	1.354	22.970	65.217	559.619
Nigeria	Observation	21	21	21	21	21	20	15
	Mean	-0.481	26.584	1.496	2.639	84.029	28.631	740.805
	Std. Dev.	0.138	0.344	0.788	0.103	2.209	5.425	22.525
	Minimum	-0.711	25.915	0.184	2.441	80.640	16.915	700.383
	Maximum	-0.213	26.957	2.900	2.764	88.680	37.441	785.261
South Africa	Observation	21	21	21	21	21	20	15
	Mean	2.027	26.429	1.401	1.132	9.929	73.224	2604.709
	Std. Dev.	0.079	0.160	1.193	0.326	2.369	6.210	174.344
	Minimum	1.804	26.125	0.205	0.387	7.720	62.857	2308.573
	Maximum	2.134	26.608	5.368	2.074	16.180	81.081	2904.276
Sudan	Observation	21	21	21	21	21	20	15
	Mean	-0.898	25.138	3.084	2.620	66.720	12.908	488.496
	Std. Dev.	0.278	0.122	1.347	0.363	7.116	4.085	45.502
	Minimum	-1.531	24.847	0.821	1.994	58.850	6.667	405.032
	Maximum	-0.605	25.301	6.318	3.255	80.420	19.118	548.822
Tunisia	Observation	21	21	21	21	21	20	15
	Mean	0.887	24.392	2.859	1.034	13.483	56.839	847.100
	Std. Dev.	0.078	0.182	1.854	0.104	1.088	6.431	64.096
	Minimum	0.756	24.054	0.899	0.912	11.820	45.714	738.469
	Maximum	1.007	24.622	9.425	1.278	16.070	68.478	943.706
Pairwise correlation	$lnCO_2$	1						
	lnPC	0.227***	1					
	FDI	-0.196**	-0.24**	1				
	PGR	-0.537***	-0.007	0.047	1			
	REN	-0.84***	-0.040	0.135	0.58***	1		
	REQ	0.137**	0.073	0.130	-0.33***	-0.30***	1	
	ENU	0.8492***	0.28**	-0.21**	-0.36***	-0.52***	0.003	1

Note: *** p<0.01, ** p<0.05, * p<0.1; $lnCO_2$ log of carbon emissions; lnPC log of GDP per capita; FDI foreign direct investment; PGR population growth; REN renewable energy; REQ regulatory quality; EN energy use.
Source: Authors' computations

methodology using FGLS, which controls for heteroscedasticity and serial correlation to estimate all our models, for robustness checks and to ensure consistency of the results we deployed the PCSE techniques which also controls for heteroscedasticity and serial correlation.

Table 3 displays descriptive statistics and pairwise correlations, revealing that Libya and South Africa exhibitthe highest CO_2 emissions. With a mean of 2.027%, South Africa shows marginally lower emissions than Libya's 2.140%. South Africa's reliance on coal for energy production contributes significantly to its CO_2 output (Yoro & Sekoai, 2016; Beidari *et al.*, 2017; Hassan, 2023). Conversely, Libya's economy heavily depends on its oil and gas industry leading to substantial CO_2 emissions from extraction, refining, and export activities (Nassar *et al.*, 2021). Both countries attract substantial FDI, with South Africa slightly surpassing Libya with a mean of 1.401% compared to 1.270% respectively. Factors such as abundant natural resources, infrastructure development opportunities, and strategic geographic locations contribute to this significant FDI inflow. Although South Africa and Libya experience similar population growth rates, their approaches to renewable energy differ significantly. South Africa exhibits a notably higher mean renewable energy usage of 9.929% compared to Libya with 2.757%. This contrast arises from South Africa's investments in renewable energy infrastructure driven by concerns about energy security, environmental sustainability, and global carbon emission reduction commitments. However, despite South Africa's emphasis on renewable energy, South Africa and Libya maintain higher overall energy usage, with averages of 2604.709kg and 2987.446kg respectively. Factors such as industrial demands, economic activities, and energy-intensive sectors like mining and manufacturing contribute to this surge. Libya, benefiting from substantial oil reserves, may rely more heavily on fossil fuels for energy generation and industrial processes.

Among the leading CO_2 emitters in Africa, Ghana leads FDI inflow with an average of 4.956%, attributed to its stable political climate and abundant natural resources, including gold, cocoa, and oil. Sudan follows with an average FDI inflow of 3.084%. The remaining countries also demonstrate significant FDI inflow, emphasizing its crucial role in driving economic development across the countries. This influx of investment presents opportunities for addressing environmental concerns such as CO_2 emissions by promoting cleaner technologies and sustainable practices.

4. Results and discussions

Table 4 displays the results of the CDS, panel unit root, and cointegration tests. The results of the Pesaran (2004) test for CSD indicate rejection of the null hypothesis of "no cross-sectional dependence" at a significance level of 1%. This implies that a shock in one of the leading CO_2 emitters in Africa might be transmitted to others. To assess the variables' stationarity, the Harris and Tzavalis (1999) unit root test and the Pesaran (2007) second-generation unit root test are utilized. The results from both tests indicate that all variables exhibit stationarity after the first difference, with statistical significance at the 1% level. Additionally, the cointegration results obtained from the Westerlund (2007) test suggest a long-run relationship among the variables at a 1% significant level.

Table 5 presents the results derived from estimating Equations 1 to 4 using FGLS in columns [1] through [4] and PCSE in columns [5] through [8]. We focused our interpretation on variables central to our study objectives: energy use (EN) and FDI. The results are consistent with our expectations $H_0\colon \varphi_1 > 0$ in both FGLS and PCSE analyses. The results reveal a significant positive association between energy use and CO_2 emissions among the leading CO_2 emitters in Africa, with statistical significance observed at the 1% level. Specifically, the results indicate that a unit increase in energy use corresponds to an average increase of 0.2% in carbon emissions among the leading CO_2 emitters in Africa. See columns [2],[4],[6] and [8]. This is in line with (Mensah *et al.*, 2021; Sikder *et al.*, 2022), who found that reliance on fossil fuel energy use to meet energy demand in Africa stimulates environmental degradation. However, the presence of a negative relationship between the non-linear square term of energy use (ENSQ) and CO_2 emissions validates the inverted U-shaped Environmental Kuznets Curve (EKC) hypothesis, with $\varphi_1 > 0\ and\ \varphi_2 < 0$ indicating an inverted U-shaped relationship in energy use among leading CO_2 emitters in Africa. This suggests that Africa's leading CO_2 emitters reach a threshold point at which the adverse effects of using non-renewable energy begin to diminish. Our analysis identifies this turning point to occur between 2760.12 and 2886.29 kg of oil equivalent per capita. The result aligns with (Destek & Sinha, 2020; Erdoğan *et al.*, 2022), who found that carbon emissions initially rise as African countries experience economic growth and energy consumption before eventually declining. This shift can be attributed to technological advancements that have made renewable energy sources more cost-effective than traditional fossil fuels. With the ongoing decline in the cost of renewable energy, it has become a more attractive option for individuals, businesses, and governments in reducing CO_2 emissions in Africa. Our results are supported by similar studies conducted in other parts of the world (Hamid *et al.*, 2021; Alsaedi *et al.*, 2022; Adeleye *et al.*, 2023).

For FDI, the result is also consistent with our expectations $H_0\colon \text{þ}_1 < 0$, indicating a significant and inverse relationship between FDI and environmental pressure among the leading CO_2 emitters in Africa, a unit increase in FDI corresponds to a reduction in CO_2 emissions ranging from 2% to 4% among the leading CO_2 emitters in Africa, as observed in columns [3], [4], [7], and [8], respectively. Our results align with (Adams *et al.*,

Table 4
CSD, Panel unit root, and Cointegration tests

Variables	Pesaran (2004) CD	Harris-Tzavalis (1999) ht		Pesearan (2007) CIPS	
		I(0)	I(1)	I(0)	I(1)
$lnCO_2$	7.978***	-0.3323	-20.3392***	0.7687	-7.0804***
lnPC	21.177***	0.7049	-24.6215***	2.1729	-6.8591***
FDI	5.773***	-5.7122***	-23.8644***	-3.9740***	-8.5165***
PGR	2.895***	-8.5348***	-18.2828***	-2.3925***	-6.3222***
REN	15.18***	0.0923	-19.8143***	-1.4884*	-5.8991***
REQ	3.066***	0.2211	-19.2192***	-0.2862	-6.9727***
EN	5.103***	-6.7051	-17.9489***	-1.5140*	-5.9247***
Westerlund (2007) cointegration test					
Variance ratio = 2.1851***					

Note: *** p<0.01, ** p<0.05, * p<0.1; $lnCO_2$ log of carbon emissions; lnPC log of GDP per capita; FDI foreign direct investment; PGR population growth; REN renewable energy; REQ regulatory quality; EN energy use.
Source: Authors' computations

Table 5
PCSE and FGLS results, total sample (Dep Var: lnCO2)

VARIABLES	FGLS, Main Analysis				PCSE, Robustness			
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
DEP. VARI.	**$lnCO_2$**	**$lnCO_2$**	**$lnCO_2$**	**$lnCO_2$**	**$lnCO_2$**	**$lnCO_2$**	**$lnCO_2$**	**$lnCO_2$**
lnPC	0.264***	-0.0144***	0.262***	-0.00130	0.265***	-0.0188**	0.265***	-0.00317
	(48.97)	(-3.021)	(37.93)	(-0.218)	(17.83)	(-2.275)	(15.66)	(-0.230)
PGR	-0.107***	0.0250***	-0.121***	0.00709	-0.123**	0.0349**	-0.149**	0.0150
	(-14.04)	(4.637)	(-11.65)	(1.203)	(-2.508)	(2.117)	(-2.555)	(1.109)
REQ	-0.00739***	-0.000864***	-0.00707***	-0.0000151	-0.00786***	-0.000526	-0.00723***	-0.00000361
	(-26.10)	(-4.097)	(-26.69)	(-0.0673)	(-9.790)	(-1.177)	(-8.037)	(-0.0688)
REN	-0.0290***	-0.0173***	-0.0294***	-0.0172***	-0.0290***	-0.0172***	-0.0287***	-0.0172***
	(-239.7)	(-229.6)	(-114.3)	(-154.7)	(-28.88)	(-79.37)	(-24.31)	(-49.07)
EN		0.00191***		0.00182***		0.00198***		0.00189***
		(60.67)		(60.53)		(17.54)		(19.36)
ENSQ		-0.000000346***		-0.000000321***		-0.000000367***		-0.000000343***
		(-36.87)		(-37.69)		(-11.59)		(-12.46)
FDI			-0.0302***	-0.0238***			-0.0437**	-0.0404**
			(-6.608)	(-5.359)			(-2.422)	(-2.382)
FDISQ			0.00219***	0.00208***			0.00354***	0.00372***
			(4.893)	(4.945)			(2.583)	(2.750)
Turning point		2760.12	6.89			2886.29	6.17	
Constant	-4.802***	0.00192	-4.694***	-0.261*	-4.788***	0.0396	-4.716***	-0.240
	(-35.36)	(0.0178)	(-27.47)	(-1.876)	(-12.63)	(0.233)	(-10.75)	(-0.767)
Observations	200	140	200	140	200	140	200	140
R-squared					0.775	0.959	0.785	0.965
No. country	10	10	10	10	10	10	10	10
Wald stat.	98642	180628	48635	143820	5290	66541	3729	41031

Note: z-statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1; $lnCO_2$ log of carbon emissions; FDI foreign direct investment; FDISQ square of foreign direct investment; lnPC log of GDP per capita; PGR population growth; REN renewable energy; RENSQ Square of renewable energy; REQ regulatory quality;
EN energy use; ENSQ Square of non-renewable energy use.
Source: Authors' computations

2020; Asongu & Odhiambo, 2021), who found that FDI inflow in Africa improves environmental quality. Our results contrast with Abdoulie and Hammami, (2017) who found that FDI inflow in Africa contributes to environmental degradation. However, the presence of a positive relationship between the non-linear square term of Foreign direct investment (FDISQ) and CO_2 emissions in both the FGLS and PCSE analyses unveils a significant positive quadratic effect, suggesting a non-linear effect of FDI translates to an increase of CO_2 emissions, as depicted in columns [3],[4],[7] and [8]. The results do not support the inverted U-shaped Environmental Kuznets Curve (EKC) hypothesis in FDI inflow, with $\beta_1 < 0 \; and \; \beta_2 > 0$ revealing a U-shaped relationship between FDI and CO_2 emission among leading CO_2 emitters in Africa. As indicated in columns [3], [4],[7] and [8]. The threshold point occurs between 6.98 and 6.17, suggesting that at 6.17% and 6.98% inflow of FDI CO_2 emission begins to rise among leading CO_2 emitters in Africa. The results align with (Shahbaz *et al.*, 2019; Asongu & Odhiambo, 2021). The results reveal that at the early stage of development leading CO_2 emitters in Africa enjoy environmental sustainability through FDI inflow but decline after the threshold point is attained.

CO_2 emissions represent a critical global issue with far-reaching environmental implications. The intervention of stakeholders is crucial for achieving carbon neutrality successfully (Sebos *et al.*, 2023). Stakeholders' insights and actions play a pivotal role in shaping strategies that are not only economically viable but also environmentally sustainable (Ioanna *et al.*, 2022). Governments and policymakers are tasked with the dual challenge of fostering economic growth while safeguarding the environment. This requires promoting renewable energy sources and implementing regulations on FDI that support green technologies and sustainable practices. International organizations play a crucial role in this effort by providing essential funding and technical expertise. They advocate for policies that harmonize economic objectives with environmental conservation, ensuring a balanced approach to achieving global sustainability goals.

Mitigation actions to reduce greenhouse gas emissions and FDI in green technologies can significantly address air pollution while promoting economic growth. Mitigation efforts, such as adopting renewable energy sources and energy-efficient technologies, directly reduce the emission of harmful pollutants, leading to improved air quality and public health (Progiou *et al.*, 2023).

The early stage of FDI inflow, the result supports the halo effect hypothesis (HEH), as FDI often involves the transfer of advanced technologies and management practices from developed countries to host countries. These technologies may include cleaner and more energy-efficient production methods, machinery, and equipment.; but after the threshold point is attained, the pollution haven hypothesis (PHH) effect begins to showcase. This positive increase may be due to industries migrating from countries with stringent environmental regulations to Africa, where regulatory enforcement may be weaker than developed countries.

5. Conclusions and Recommendations

5.1 Conclusions

Carbon emissions have become a pressing global concern because of its contribution to climate change and environmental degradation. Despite Africa being a relatively minor contributor to global carbon emissions, it faces increasing pressure to mitigate its carbon footprint, especially as it strives for economic development. Given the urgency to tackle climate change, especially by reducing CO_2 emissions, this study focuses on Africa's leading CO_2 emitters from 2000 to 2020. The study employed an innovative analysis of unbalanced panel data, utilizing sophisticated econometric techniques the contemporaneous correlation methodology, which are the FGLS, and the PCSE to uncover insights. The study confirms the existence of an Energy-Kuznets Curve among the leading CO_2 emitters in Africa. This curve suggests that as economies initially develop, energy use and associated CO_2 emissions increase but beyond certain threshold, emissions begin to decrease as cleaner technologies and more sustainable practices are adopted. The research also finds evidence of a U-shaped relationship between FDI and carbon emissions among the leading CO_2 emitters in Africa. This curve suggests that initially, FDI could facilitate the adoption of cleaner technologies and practices resulting in reduced CO_2 emissions. However, beyond a certain threshold, FDI inflows increase emissions due to industrial activities. The study identifies these crucial turning points at 2760.12kg and 2886.29kg of oil equivalent per capita for energy use and 6.89% and 6.17% for FDI inflow, respectively. These turning points represent thresholds beyond which the relationship between energy use, FDI, and CO_2 emissions changes significantly indicating potential policy intervention points.

The study's contributions to the field is substantial; the affirmation of the validity of the Energy-Kuznets Curve in the presence of heightened FDI inflow suggests that economic development can lead to emission reduction under certain conditions. Highlighting the detrimental impact of escalating energy consumption on the FDI emission relationship, emphasizing the need for energy efficiency measures and cleaner energy sources. Underscoring the adverse environmental repercussions of elevated FDI, indicating the importance of sustainable investment practices and environmental regulations.

Moreover, the research represents a pioneering effort by being the first to employ such advanced econometric techniques, FGLS and PCSE to analyze the nexus between energy use, FDI, and CO_2 emissions within Africa's context. By enriching the existing literature, this study provides valuable insights for policymakers, researchers, and stakeholders striving to address climate change and promote sustainable development in Africa and beyond.

Other countries can utilize the findings of this study in several ways. One is the validation of the energy-Kuznets curve; other developing countries can examine their energy consumption and CO_2 emission patterns to see if they follow the energy-Kuznets curve. This can inform their economic and environmental policies, ensuring that growth does not come at the expense of environmental degradation. Understanding the U-shaped relationship between FDI and CO_2 emissions can help other countries to manage their foreign investments more effectively. By identifying the thresholds where FDI shifts from being beneficial to detrimental, countries can create targeted policies to attract sustainable investments. The identified thresholds for energy use and FDI inflows provide actionable points where policy interventions can be most effective. Countries can tailor their regulations and incentives to maintain energy use and FDI below these thresholds to mitigate environmental impacts.

5.2 Recommendations and Future Remarks

These findings have important implications for Africa's policy formulation and economic development strategies. The results support the halo effect hypothesis at the early stages of FDI inflows, suggesting that FDI can bring about environmental benefits by transferring advanced technologies and management practices. However, once the threshold point is surpassed, the pollution haven hypothesis comes into play, as industries may relocate to Africa to take advantage of weaker environmental regulations. Policymakers must balance attracting FDI for economic growth and ensuring environmental sustainability by implementing effective regulatory frameworks and promoting cleaner production methods.

Governments and policymakers should promote investment in renewable energy sources, including wind, solar, hydroelectric, and geothermal power. These sources are abundant in many African countries and can provide clean energy while reducing reliance on fossil fuels.

To achieve the 2030 United Nations Sustainable Development Goal (SDG) 13 objectives, which emphasize the urgent need to address climate change and its consequences, governments must set clear and ambitious objectives for decreasing CO2 emissions and shifting towards renewable energy alternatives. These objectives should be in harmony with the targets outlined in the Paris Agreement, which aims to constrain global warming to below 2^0C.

Author Contributions: Conceptualization, Yahya Njie; Methodology, formal analysis, Yahya Njie, Weidong Wang; Writing—original draft Yahya Njie, Lin Liu; Supervision, resources, project administration Weidong Wang; Writing—review and editing, Yahya Njie, Lin Liu, Abdullah; Validation, Weidong Wang, Abdullah. All authors have read and agreed to the published version of the manuscript.

Funding: The author(s) received no financial support for this article's research, authorship, and publication.

Conflicts of Interest: The authors declare no conflict of interest.

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, *29*(28), 42539-42559. https://doi.org/10.1007/s11356-022-19718-6

Abdouli, M., & Hammami, S. (2017). Investigating the causality links between environmental quality, foreign direct investment and economic growth in MENA countries. *International Business Review*, 26(2), 264-278. https://doi.org/10.1016/j.ibusrev.2016.07.004

Adams, S., Boateng, E., & Acheampong, A. O. (2020). Transport energy consumption and environmental quality: does urbanization matter?. *Science of the Total Environment*, 744, 140617. https://doi.org/10.1016/j.scitotenv.2020.140617

Adeleye, B. N., Akam, D., Inuwa, N., James, H. T., & Basila, D. (2023). Does globalization and energy usage influence carbon emissions in South Asia? An empirical revisit of the debate. *Environmental Science and Pollution Research*, 30(13), 36190-36207. https://doi.org/10.1007/s11356-022-24457-9

Alsaedi, M. A., Abnisa, F., Alaba, P. A., & Farouk, H. U. (2022). Investigating the relevance of Environmental Kuznets curve hypothesis in Saudi Arabia: towards energy efficiency and minimal carbon dioxide emission. *Clean Technologies and Environmental Policy*, 24(4), 1285-1300. https://doi.org/10.1007/s10098-021-02244-3

Appiah, M., Li, F., & Korankye, B. (2021). Modeling the linkages among CO2 emission, energy consumption, and industrialization in sub-Saharan African (SSA) countries. *Environmental Science and Pollution Research*, *28*, 38506-38521. https://doi.org/10.1007/s11356-021-12412-z

Asongu, S., & Odhiambo, N. M. (2021). Trade and FDI thresholds of CO2 emissions for a Green economy in sub-Saharan Africa.

International Journal of Energy Sector Management, 15(1), 227-245. https://doi.org/10.1108/IJESM-06-2020-0006

Bakhsh, S., Yin, H., & Shabir, M. (2021). Foreign investment and CO2 emissions: do technological innovation and institutional quality matter? Evidence from system GMM approach. *Environmental Science and Pollution Research*, 28(15), 19424-19438. https://doi.org/10.1007/s11356-020-12237-2

Beidari, M., Lin, S. J., & Lewis, C. (2017). Decomposition analysis of CO2 emissions from coal-sourced electricity production in South Africa. *Aerosol and Air Quality Research*, 17(4), 1043-1051. https://doi.org/10.4209/aaqr.2016.11.0477

Belaïd, F., & Zrelli, M. H. (2019). Renewable and nonrenewable electricity consumption, environmental degradation and economic development: evidence from Mediterranean countries. *Energy Policy*, 133, 110929. https://doi.org/10.1016/j.enpol.2019.110929

Blau, J. (2017). The Paris Agreement: climate change, solidarity, and human rights. *Springer*. https://doi.org/10.1007/978-3-319-53541-8

Byaro, M., Mafwolo, G., & Mayaya, H. (2022). Keeping an eye on environmental quality in Tanzania as trade, industrialization, income, and urbanization continue to grow. *Environmental Science and Pollution Research*, 29(39), 59002-59012. https://doi.org/10.1007/s11356-022-19705-x

Ciftci, C., & Durusu-Ciftci, D. (2022). Economic freedom, foreign direct investment, and economic growth: The role of sub-components of freedom. *The Journal of International Trade & Economic Development*, 31(2), 233254. https://doi.org/10.1080/09638199.2021.1962392

Destek, M. A., & Sinha, A. (2020). Renewable, nonrenewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organization for economic Co-operation and development countries. *Journal of cleaner production*, 242, 118537. https://doi.org/10.1016/j.jclepro.2019.118537

Djellouli, N., Abdelli, L., Elheddad, M., Ahmed, R., & Mahmood, H. (2022). The effects of nonrenewable energy, renewable energy, economic growth, and foreign direct investment on the sustainability of African countries. *Renewable Energy*, 183, 676-686. https://doi.org/10.1016/j.renene.2021.10.066

Duodu, E., Kwarteng, E., Oteng-Abayie, E. F., & Frimpong, P. B. (2021). Foreign direct investments and environmental quality in sub-Saharan Africa: the merits of policy and institutions for environmental sustainability. *Environmental Science and Pollution Research*, 28, 66101-66120. https://doi.org/10.1007/s11356-021-15288-1

Erdoğan, S., Onifade, S. T., Altuntaş, M., & Bekun, F. V. (2022). Synthesizing urbanization and carbon emissions in Africa: how viable is environmental sustainability amid the quest for economic growth in a globalized world?. *Environmental Science and Pollution Research*, 29(16), 24348-24361. https://doi.org/10.1007/s11356-022-18829-4

Esseghir, A., & Khouni, L. H. (2014). Economic growth, energy consumption and sustainable development: The case of the Union for the Mediterranean countries. *Energy*, 71, 218-225. https://doi.org/10.1016/j.energy.2014.04.050

Filho, W. L., Wall, T., Salvia, A. L., Dinis, M. A. P., & Mifsud, M. (2023). The central role of climate action in achieving the United Countries' Sustainable Development Goals. *Scientific Reports*, 13(1), 20582. https://doi.org/10.1038/s41598-023-47746-w

Hamid, I., Alam, M. S., Murshed, M., Jena, P. K., Sha, N., & Alam, M. N. (2021). The roles of foreign direct investments, economic growth, and capital investments in decarbonizing the economy of Oman. *Environmental Science and Pollution Research*, 1-17. https://doi.org/10.1007/s11356-021-17246-3

Harris, R. D. F., and E. Tzavalis. 1999. Inference for unit roots in dynamic panels where the time dimension is fixed. *Journal of Econometrics* 91: 201–226

Hassan, A. S. (2023). Coal mining and environmental sustainability in South Africa: do institutions matter?. *Environmental Science and Pollution Research*, 30(8), 20431-20449. https://doi.org/10.1007/s11356-022-23585-6

Jorgenson, A. K., Alekseyko, A., & Giedraitis, V. (2014). Energy consumption, human well-being and economic development in central and eastern European nations: A cautionary tale of *sustainability*. *Energy Policy*, 66, 419-427. http://dx.doi.org/10.1016/j.enpol.2013.11.020

Kebede, E., Kagochi, J., & Jolly, C. M. (2010). Energy consumption and economic development in Sub-Sahara Africa. *Energy economics*, 32(3), 532-537. https://doi.org/10.1016/j.eneco.2010.02.003

Kuznets, S. (1955). Economic Growth and Income Inequality: *Am. Econ. Rev.* **45**, 1–28. URL: scholar.google.com

Kyriakopoulos, G. L., Sebos, I., Triantafyllou, E., Stamopoulos, D., & Dimas, P. (2023). Benefits and synergies in addressing climate change via the implementation of the common agricultural policy in Greece. *Applied Sciences*, 13(4), 2216. https://doi.org/10.3390/app13042216

Ioanna, N., Pipina, K., Despina, C., Ioannis, S., & Dionysis, A. (2022). Stakeholder mapping and analysis for climate change adaptation in Greece. *Euro-Mediterranean Journal for Environmental Integration*, 7(3), 339-346. https://doi.org/10.1007/s41207-022-00317-3

Martín-Ortega, J. L. et al (2024). Enhancing Transparency of Climate Efforts: MITICA's Integrated Approach to Greenhouse Gas Mitigation. *Sustainability*, 16(10), 4219. https://doi.org/10.3390/su16104219

Mensah, I. A., Sun, M., Omari-Sasu, A. Y., Gao, C., Obobisa, E. S., & Osinubi, T. T. (2021). Potential economic indicators and environmental quality in African economies: new insight from cross-sectional autoregressive distributed lag approach. *Environmental Science and Pollution Research*, 28(40), 56865-56891. https://doi.org/10.1007/s11356-021-14598-8

Murshed, M., Mahmood, H., Ahmad, P., Rehman, A., & Alam, M. S. (2022). Pathways to Argentina's 2050 carbon-neutrality agenda: the roles of renewable energy transition and trade globalization. *Environmental Science and Pollution Research*, 29(20), 29949-29966. https://doi.org/10.1007/s11356-021-17903-7

Nassar, Y. F., Salem, M. A., Iessa, K. R., AlShareef, I. M., Ali, K. A., & Fakher, M. A. (2021). Estimation of CO 2 emission factor for the energy industry sector in Libya: A case study. *Environment, Development and Sustainability*, 23, 13998-14026. https://doi.org/10.1007/s10668-021-01248-9

Nguyen, K. H., & Kakinaka, M. (2019). Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. *Renewable Energy*, 132, 1049-1057. https://doi.org/10.1016/j.renene.2018.08.069

Nyiwul, L. (2021). Climate change adaptation and inequality in Africa: Case of water, energy and food insecurity. *Journal of Cleaner Production*, 278, 123393. https://doi.org/10.1016/j.jclepro.2020.123393

Odhiambo, N. M. (2022). Foreign direct investment and economic growth in Kenya: An empirical investigation. *International Journal of Public Administration*, 45(8), 620-631. https://doi.org/10.1080/01900692.2021.1872622

Ojewumi, S. J., & Akinlo, A. E. (2017). Foreign direct investment, economic growth and environmental quality in sub-Saharan Africa: a dynamic model analysis. *African Journal of Economic Review*, *5*(1), 48-68.

Papadogiannaki, S., Liora, N., Parliari, D., Cheristanidis, S., Poupkou, A., Sebos, I., ... & Melas, D. (2023). Evaluating the impact of COVID-19 on the carbon footprint of two research projects: A comparative analysis. *Atmosphere*, 14(9), 1365. https://doi.org/10.3390/atmos14091365

Pata, U. K., & Aydin, M. (2020). Testing the EKC hypothesis for the top six hydropower energy-consuming countries: Evidence from Fourier Bootstrap ARDL procedure. *Journal of Cleaner Production*, 264, 121699. https://doi.org/10.1016/j.jclepro.2020.121699

Pata, U. K., & Caglar, A. E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break. *Energy*, 216, 119220. https://doi.org/10.1016/j.energy.2020.119220

Pesaran MH (2004) General diagnostic tests for cross section dependence in panels. University of Cambridge, Faculty of Economics, Cambridge Working Papers in Economics No. 0435. https://doi.org/10.1007/s00181-020-01875-7

Pesaran MH (2007) A Simple unit root test in the presence of cross section dependence. *J Appl Econ* 22:265–312. https://doi.org/10.1002/jae.951

Progiou, A., Liora, N., Sebos, I., Chatzimichail, C., & Melas, D. (2023). Measures and policies for reducing PM exceedances through the use of air quality modeling: the case of Thessaloniki, Greece. *Sustainability*, 15(2), 930. https://doi.org/10.3390/su15020930

Ritchie, H., Roser, M., & Rosado, P. (2020). CO_2 and greenhouse gas emissions. Our world in data.

Shahbaz, M., Balsalobre-Lorente, D., & Sinha, A. (2019). Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *Journal of cleaner production*, 217, 603 614.https://doi.org/10.1016/j.jclepro.2019.01.282

Sikder, M., Wang, C., Yao, X., Huai, X., Wu, L., KwameYeboah, F., ... & Dou, X. (2022). The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO2 emissions in developing countries: evidence from the Panel ARDL approach. *Science of the Total Environment*, 837, 155795. https://doi.org/10.1016/j.scitotenv.2022.155795

Progiou, A., Liora, N., Sebos, I., Chatzimichail, C., & Melas, D. (2023). Measures and policies for reducing PM exceedances through the use of air quality modeling: the case of Thessaloniki, Greece. *Sustainability*, 15(2), 930. https://doi.org/10.3390/su15020930

Salahuddin, M., Habib, M. A., Al-Mulali, U., Ozturk, I., Marshall, M., & Ali, M. I. (2020). Renewable energy and environmental quality: A second-generation panel evidence from the Sub-Saharan Africa (SSA) countries. *Environmental research*, 191, 110094. https://doi.org/10.1016/j.envres.2020.110094

Sebos, I., Progiou, A., Kallinikos, L., Eleni, P., Katsavou, I., Mangouta, K., & Ziomas, I. (2016). Mitigation and adaptation policies related to climate change in Greece. *Energy, Transportation and Global Warming*, 35-49. https://doi.org/10.1007/978-3-319-30127-3_4

Sebos, I., Nydrioti, I., Katsiardi, P., & Assimacopoulos, D. (2023). Stakeholder perceptions on climate change impacts and adaptation actions in Greece. *Euro-Mediterranean Journal for Environmental Integration*, 8(4), 777-793. https://doi.org/10.1007/s41207-023-00396-w

Ssali, M. W., Du, J., Mensah, I. A., & Hongo, D. O. (2019). Investigating the nexus among environmental pollution, economic growth, energy use, and foreign direct investment in 6 selected sub-Saharan African countries. *Environmental Science and Pollution Research*, 26, 11245-11260. https://doi.org/10.1007/s11356-019-04455-0

Sustainable Development Goal 2030 URL

Teske, S. (2019). Achieving the Paris climate agreement goals: Global and regional 100% renewable energy scenarios with non-energy GHG pathways for+ 1.5 C and+ 2 C (p. 491). *Springer Nature*. https://doi.org/10.1007/978-3-030-05843-2

Westerlund J (2007) Testing for error correction in panel data. Oxford Bulletin of Economics and Statistics 69(6):709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Yassine, C., & Sebos, I. (2024). Quantifying COVID-19′ s impact on GHG emission reduction in Oman's transportation sector: A bottom-up analysis of pre-pandemic years (2015–2019) and the pandemic year (2020). *Case Studies on Transport Policy*, 16, 101204. https://doi.org/10.1016/j.cstp.2024.101204

Yoro, K. O., & Sekoai, P. T. (2016). The potential of CO2 capture and storage technology in South Africa's coal-fired thermal power plants. *Environments*, 3(3), 24. https://doi.org/10.3390/environments3030024.