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DOES GREEN INDUSTRIALIZATION MATTER FOR CARBON EMISSION REDUCTION IN AFRICA?

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Abstract

This study investigated the role of sustainable green industrialization in mitigating carbon emissions while promoting long-term development in Africa, using panel data from 48 countries covering the period 2000 to 2022. The data were analyzed using Augmented Mean Group (AMG), Common Correlated Effect Mean Group (CCEMG), and Method of Moments Quantile Regression (MMQR), which were second-generation econometric techniques that accounted for cross-sectional dependence and slope heterogeneity across countries. The findings revealed that green industrialization, proxied by renewable energy consumption, significantly reduced CO_2 *emissions across Africa, thereby confirming its crucial role in aligning economic growth with environmental sustainability. In contrast, industrial value added exerted a positive and significant effect on* CO_2 *emissions, reflecting the energy-intensive nature of industrial processes in the region. Similarly, foreign direct investment (FDI) was found to contribute to higher emissions, as inflows were often directed towards fossil-fuel-dependent sectors such as oil, gas, and heavy manufacturing. Furthermore, political instability and violence were shown to exacerbate* CO_2 *emissions by discouraging renewable energy investments and prolonging reliance on polluting production methods. Based on these findings, the study recommended that African governments should adopt green industrialization as a central pillar of their development agenda, enact robust carbon pricing mechanisms to discourage reliance on fossil fuels, and provide targeted incentives for research, development, and deployment of renewable energy technologies.*

Keywords: *Green Industrialization,* CO_2 *emissions, Renewable energy consumption, Africa.*

JEL Classification: O13, Q01, Q54, Q58.

Introduction

The international community under the banner of the United Nations adopted the ambitious Sustainable Development Goals (SDGs). Target 4.7 and 12.8 of the aims to guarantee that individuals worldwide possess the necessary knowledge, education, and consciousness for sustainable development and lifestyles that align with the natural environment. Meanwhile, Target 9.2 centers on advancing inclusive and sustainable industrialization (United Nations, 2015). In the earnest pursuit of attaining these objectives, the matter of carbon emissions, recognized as a substantial catalyst of climate change, manifests as a precarious outcome stemming from industrialization (Li et al., 2023; Kwakwa, 2023). This occurrence presents a formidable health risk to both communities and the natural environment. Consequently, various governments, scholars and researchers have dedicated their efforts to exploring strategies aimed at mitigating carbon emissions and curbing their adverse effects on the environment. As the world grapples with the ever-pressing issue of climate change, the imperative of this goal has never been clearer.

In a world acutely aware of the repercussions of inaction in the face of pressing environmental challenges, nations are diligently charting new paths towards sustainable development, with a paramount objective of harmonizing economic growth with environmental preservation (Wiredu et al., 2023; Amowine, 2023). A significant facet of this global effort revolves around the exploration of renewable energy sources as a pivotal input in industrial production. However, while African countries share this overarching goal of sustainable development and recognize the potential of renewable energy, the extent to which they have been able to fully rely on these resources varies widely due to a spectrum of challenges, including but not limited to financial constraints, infrastructural limitations, and technology access disparities (Amir & Khan, 2022; Tembo et al., 2023).

In pursuit of the imperative goal of curtailing carbon emissions and addressing the formidable challenge of climate change, various African governments have undertaken a range of strategic policies and initiatives. These endeavors involve multifaceted approaches, including the establishment of dedicated funding mechanisms such as the AfD Green Fund, which bolsters investments in energy efficiency and renewable energy ventures. Furthermore, comprehensive programs targeting energy efficiency improvements across diverse sectors, vigorous promotion of renewable energy sources, and the crucial expansion of rural electrification networks have been diligently pursued. Additionally, countries such as Morocco and South Africa have explored the adoption of carbon pricing mechanisms as a market-driven approach to incentivize emissions reduction, while afforestation and reforestation initiatives aim to enhance carbon sequestration (Epule et al., 2021). However, despite the substantial investments in these policies, it remains disheartening to observe that the intensity of carbon emissions continues to persist in many African countries. This enduring challenge have implications on economic, social, and environmental factors in the continent. For instance, the United Nations (2023) estimate that 3% of carbon emissions can be attributed to African countries, however, but the continent is exposed to the impact of extreme weather linked to climate change as a consequence of carbon emissions.

Nevertheless, as African nations embark on their journey towards a more environmentally friendly and healthier planet, they stand at a critical juncture, grappling with the question of whether green industrialization truly offers a path to reducing carbon emissions and fostering sustainable development. The existing body of research further complicates this dilemma, as it yields inconclusive results. For instance, studies conducted by Acheampong (2018), Adebayo & Ullah (2023), Apergis et al. (2023), Idowu et al. (2023), Hao (2022), Batool et al. (2022), and Huang et al. (2021) assert that renewable energy contributes to carbon emission reduction. In opposition, Sharif et al. (2023) and Chen et al. (2022) argue that in countries where fossil fuel usage is promoted over renewable energy, the relationship tends to be positive. Regarding the direction of causality, the literature also lacks consensus, as evidenced by the studies conducted by Zhang et al. (2023), Apergis et al. (2023), Dissanayake et al. (2023), Mehmood et al. (2022), Wu et al. (2022), Chen et al. (2022), and Asiedu et al. (2021). The inconclusive findings in the literature necessitate the need for further investigation.

Consequently, this study investigates the effect of green industrialization on carbon emission in Africa. This paper contributes to the existing literature in the following ways. First, this study comprehensively investigates the relationship between green industrialization and CO_2 emissions in African countries, contributing to a previously unexplored research gap. Also, it examines the impact of green industrialization on CO_2 emissions by employing a range of econometric techniques, that include the novel Method of Moments Quantile Regression (MMQR), Augmented Mean Group and the Common Correlated Effect Mean Group to determine the effect of green industrialization on carbon emission and the Dumitrescu-Hurlin panel causality approach along with the Time-Varying Granger causality to determine the direction of causality both in group specific and country level. Importantly, this combination of techniques is relatively unexplored in the existing literature, particularly within the context of the sampled African economies, to the best of my knowledge.

Aside from the introduction, the rest of this study is structured as follows: Section 2 provides a review of relevant literature, Section 3 presents the data and methodology, Section 4 offers the empirical results, and Section 5 concludes the study.

Literature Review

Green Industrialisation

Green industrialisation refers to the transformation of traditional industrial practices into environmentally sustainable and ecologically responsible ones through the use of cleaner technologies, green energy sources, resource-efficient production methods, and circular economy principles (Pavlyuk, 2023; Jensen & Whitfield (2022). Mehmood et al., (2023) posit that green industrialization entails a shifting from intensive use of primary energy particularly fossil fuels that pollutes the environment to alternative and efficient energy utilization. Altenburg & Rodrik (2017) views green industrialization as the process of transforming the structure of production and consumption in an economy towards activities that generate lower levels of greenhouse gas emissions and environmental degradation, while enhancing social welfare and human development. The objective of green industrialization to promote sustainable growth while simultaneously ensuring that the negative effects of industrialisation on the environment are brought to minimum levels (Naqvi et al., 2023)

According to the United Nations Industrial Development Organization (UNIDO, 2009 & 2011), green industrialization can be understood from two dimensions: self-greening industries and green enterprises. Self-greening industries refers to those industries that take steps to reduce their environmental impact by improving their industrial processes while minimizing their product-related environmental effects. Green enterprises, on the other hand, are industries that create or expand their businesses by providing environmental goods and services that promote sustainability within industries and the broader economy. Green enterprises contain various activities, such as manufacturing renewable energy equipment, recycling materials, managing waste, producing pollution control devices, as well as offering environmental and energy consulting services.

Figure 1. shows the trend of the utilization of green energy in Africa between 2000-2022.

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The data shows that the use of green energy in Africa declined consistently from a value of 3,191.45 to a low of 2,778.27 in 2019, a fall of about 12.9% over the 20-year period. The data also depicts that the use of green and alternative energy sources in Africa increased slightly by 1.2 % from 2,812.56 in 2020 to 2,807.58 in 2021. This represents an increase of 1.2% from the low level in 2019. The gradual decline in the total green energy usage in relation to total energy utilization in the past two decades could be related to inadequate policies and infrastructure to support renewable energy development and integration (Shen et al., 2023; Iweh et al., 2023).

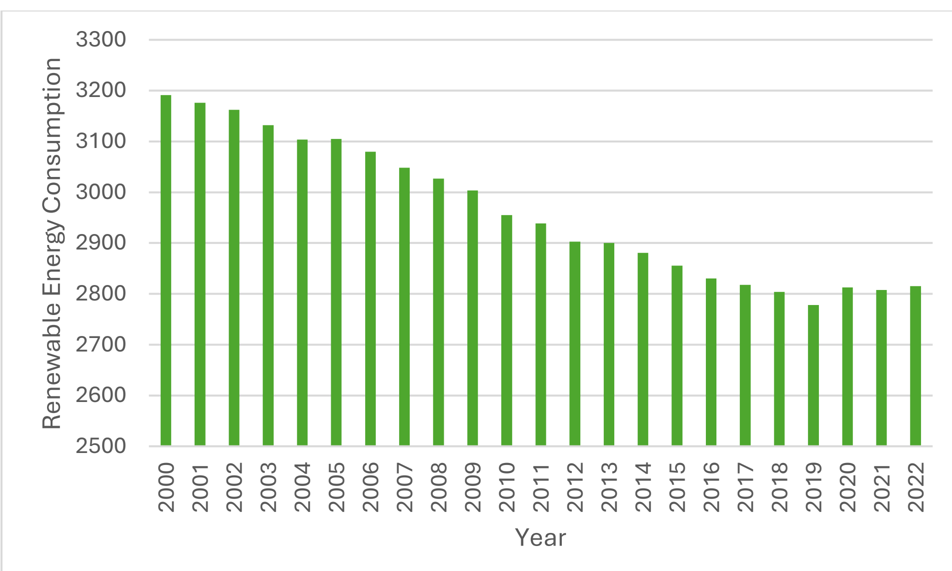

Figure 2. Green Energy Utilization in Africa: 2000-2022 (% of total energy consumed for the period):

Source: World Development Indicators (2022)

Carbon Emission

Carbon emissions is the indiscriminate release of greenhouse gases (GHGs), including carbon dioxide (CO_2) as a by-product of production, industrial processes, transportation into the Earth's stratosphere (Yoro, 2020). The emission of carbon dioxide into the stratosphere contributes to the greenhouse effect by intensifying the mechanism through which the Earth traps heat, consequently resulting in global climate change (Fagodiya et al., 2023; Wadanambi et al., 2020). Carbon emissions is measured as carbon dioxide (CO2) emissions in kilotons (kt). Carbon emissions have far-reaching and profound implications, impacting both the natural environment and human society (Evans et al., 2023). Consequence of carbon emissions include extreme weather events, heatwaves, droughts, wildfires, floods, melting glaciers, increased pest outbreaks, reduced agricultural yields. and loss of biodiversity (Roy, 2023; Yun & Ülkü, 2023; Abbass et al., 2022; Bandh et al., 2021)

Figure 2. shows the trend of total carbon emission by African countries between 2000-2022. The data shows that the total CO_2 emissions in Africa increased continuously from 875,657 kilotons in 2000 to a peak of 1,462,905 kilotons in 2019. This represents a growth of 67% over the 20-year period. However, the data also shows that the CO_2 emissions in Africa declined sharply in 2020 and 2021, dropping to 1,345,496 kilotons and 1,246,471 kilotons respectively. This represents a decrease of 15% from the peak level in 2019. The data for 2022 indicates a further decline to 1,142,790 kilotons, which is the lowest level since 2007.

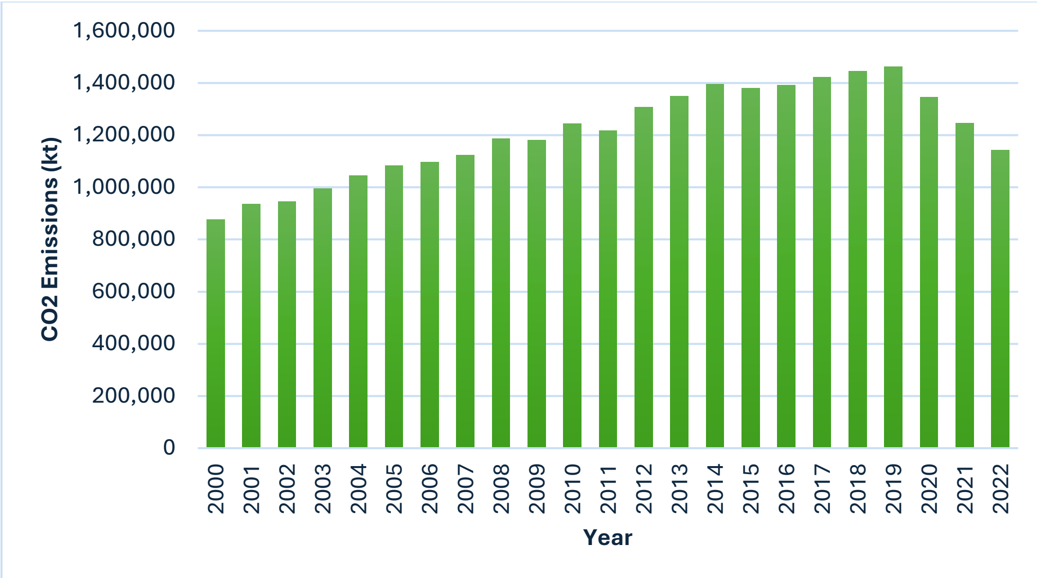

Figure 2. CO2 Emissions in Africa: 2000-2022

Source: World Development Indicators (2022)

Empirical

Mehmood et al., (2023) investigates the extent to which of the adoption and utilization of green energy influences on carbon intensity. They analysed secondary data relating to the Pakistani economy for the period 1975-2020. The Robust Least Squares estimation technique, Granger causality analysis, and Innovation Accounting Matrix was used to analyse the data. The result suggest that adoption and utilization of green energy green reduces carbon intensity. Additional findings suggest positive impacts of investment in research and development, inbound FDI as well as technical innovation on carbon intensity. Result from the causality test suggest that inward foreign direct investment drives environmental regulations while green industrial transformation drives foreign direct investment and R & D expenditures.

Raihan (2023) explore the relationship among the use of energy use, economic expansion, urbanization, and productivity in the tourism and agricultural sectors in Philippines. Through the Dynamic Ordinary Least Squares (DOLS) approach, the study analysed data spanning 1990-2020. The result demonstrate that economic expansion, urban development, industrial activities, and tourism contributes to increased CO_2 emissions. Also, renewable energy consumption, agricultural sector output, and forest area was shown to reduce carbon emissions.

Adebayo et al., (2023) investigate co-movement between carbon emissions and energy utilization among BRICS economies. The study takes disaggregated look at nonrenewable and green energy utilization. Quarterly data spanning 1990-2019 were analysed. A Wavelet Coherence (WC) method was used to analyse relationships and the direction of movement between the variables. According to the findings, a strong positive link exists between carbon emissions and economic progress, although the link dissipates over time for Russia and South Africa. Findings also shows that coal energy usage consistently and strongly contributes to increased CO_2 emissions across all BRICS nations.

Fang (2023) study economic complexity, investment in renewable energy, green innovation, industrialization and environmental pollution from carbon emissions in the Chinese economy. Data spanning 2005 to 2019 were obtained and analysed. The study adopted the Generalized Method of Moments (GMM) as the method of stimation. Empirical results indicate that economic complexity, investments in renewable energy, innovation in green technology, and industrial framework reduces led to reduction in carbon emissions.

Mumuni & Mwimba (2023) examine focus on the relationship among green energy utilization, rents from natural resources and economic expansion in Africa. In a panel approach, the study analysed empirical data for 24 African countries covering 1990-2020. Panel ARDL and the Feasible Generalized Least Squares (FGLS) were adopted as the methods of estimation. Findings reveal that green energy utilization enhances economic expansion in the long-run. Also, carbon emission was found to improve economic progress. Additionally, the use of fossil fuel negatively impacts on growth while natural resource rents constrain long-term growth in Africa. Although, mineral rents display potentials for long-term growth enhancement in Africa.

Edziah et al., (2022) examine how selected exogenous technological factors influences carbon emissions in sub-Saharan Africa. The study employed data for eighteen countries spanning 1995 to 2017. Variables used were carbon emissions, importation of machinery and equipment, spillovers from research and development, foreign direct investment, and utilization of alternative energy. The Dynamic Specific Common Correlated

Effect (DCCE) was used to analyse the data. Analysis of results reveal importation of machinery, FDI and utilization of alternative energy lowers the emission of carbon dioxide significantly. Also, findings show that foreign R&D increases carbon emissions in sub-Saharan Africa.

Mentel et al., (2022) study industrialisation, green energy, and carbon emissions in Africa. By adopting a panel approach, the study estimated data covering 2000-2015 for countries in Africa. The Generalised Method of Moments (GMM) was employed to analyse the data. The findings suggest a significant positive relationship between industrialisation and CO_2 emissions. However, renewable electricity output was found to reduces carbon emissions. Moreover, findings show that green energy sector positively reduces the influence of industry value-added on carbon emissions.

Oladipupo et al., (2022) assess the role of globalization and renewable energy consumption in environmental damage in South Africa. The study analysed data covering 1970 and 2018. The Quantile-on-Quantile Regression (QQR) method was applied to the data. The results indicate that in most quantiles, non-green energy consumption, globalization, and economic expansion damages the environment, while the utilization of renewable significantly reduces carbon emissions across the quantiles.

Adebayo et al., (2022) investigate how green energy utilization impacts on demand-based carbon emissions in emerging economies. A cross-sectional approach was employed to study data from 1990-2018. The Common Correlated Effect Mean Group (CCEMG), Augmented Mean Group (AMG) and the Dumitrescu Hurlin (HD) causality test were adopted as estimation techniques. Findings indicate that economic expansion and non-renewable fuel utilization results in environmental damage, while globalization and green energy adoption reduces environmental damage. Also, a unidirectional causality funning from globalization, economic growth and green energy utilization to demand-based carbon emissions.

Maji & Adamu (2021) examine the effects of green energy usage in enhancing environmental quality in Nigeria. Data covering 1989 to 2019 were sourced and estimated through the FMOLS technique. Findings signify that renewable energy utilization is detrimental to the quality of the environmental in in the agricultural, manufacturing, construction and oil sectors. Estimates also show green energy consumption improves the quality of the environmental in the public services, transportation, housing, commercial sectors.

Yang et al., (2021) investigate the interrelations between manufacturing output and CO2 emissions. The Finite Mixture technique was used to analyse for 25 economic subsectors in 38 countries for the period 2000-2014. Empirical findings positive impacts of manufacturing output on carbon emissions. However, findings confirm that the use of alternative energy weakens the positive effect of manufacturing growth on CO_2 emissions. Estimates also indicate that increased adoption of alternative energy source can help mitigate the environmental impact of manufacturing growth.

Wu et al., (2020) looks at causal effects of integrating global value chains (GVC), the utilization of alternative usage and carbon emissions. The data used in the study spanned 1990 to 2015 and covers 172 economies. Empirical findings suggest that integrating global value chains reduces the utilization of renewable energy in most regions. Although, the result did not hold for the Middle Eastern regions and also in North African sub-Saharan Africa. Also, no causality was found between GVC and carbon emissions in most regions.

Theoretical Framework

The theoretical underpinning for this study is the Ecological Kuznets Curve (EKC) and the IPAT model.

The EKC state that a non-linear relationship exists between environmental dispoliation and economic growth. The theory posit that at the initial stage of industrialisation, economies prioritize economic growth and employment over environmental concerns at the expense of environmental considerations, resulting in the relaxation of environmental regulations, rapid economic expansion, resource-intensive production, and increased environmental pollution (Zhou et al., 2023). Subsequently, as communities aspire to a higher quality of life, environmental issues gain importance, prompting stringent regulations, the development of clean technologies, and a shift away from polluting industries (Peng et al., 2023). However, the EKC asserts that as the economy progresses, research and development initiatives gradually substitute polluting technologies with cleaner alternatives, resulting in favorable environmental outcomes (Saia, 2023).

The IPAT model by Holdren & Ehrlich (1974) tries to explain the causes of environmental degradation and to explore its potential solutions. In the model, the effect of humans on the environment is determined by technology population, and affluence (Yilanci et al., 2023);

$$I = P \, x \, A \, x \, T \tag{1}$$

In Equation (1), I denote environmental impact, P signifies population, A is affluence, and T represent technology. In the model, the environment is viewed as self-renewing with the capacity to withstand specific levels of shocks.

Where the cumulative impact (I) is within this capacity, then the influence of population (P), affluence (A), and technology (T) on the environment are considered sustainable (Rehman et al., 2023). The cumulative impact exceeds the environment's carrying capacity, the environments capability to endure the impacts may be compromised resulting in lowered carrying capacity with potential negative implications.

Material and Method

This study used panel data of 48 African countries that include, Benin, Cote d'Ivoire, Cabo Verde, Burkina Faso, The Gambia, Ghana, Guines-Bissau, Mali, Mauritania, Niger, Nigeria, Liberia, Sierra Leone, Senegal, Togo, Zimbabwe, Burundi, Comoros, Djibouti, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Uganda, Tanzania, Zambia, Angola, Cameroon, Chad, Central African Republic, Congo, Dem. Rep., Congo, Rep, Equatorial Guinea, Gabon, Sao Tome and Principe, Botswana, Lesotho, Namibia, South Africa, Switzerland, Algeria, Egypt, Arab Rep, Morrocco, Sudan and Tunisia for the period covering 2000 to 2022. Data for 2022 of some countries were projected. The selected time scope and country scope is premised on data availability. The variables adopted in this study are CO_2 emissions (kt), Renewable energy consumption (% of total final energy consumption), Political Stability and Absence of Violence/Terrorism: Estimate, Foreign direct investment, net inflows (% of GDP), and Industry (including construction), value added per worker (constant 2015 US$). All the data were sourced from the World Bank Development Indicator.

Specification of Model and the Method of Estimation

CO2 emissions, a significant environmental concern, are central to this study's focus, and as a result, the model takes the form of a comprehensive framework for assessing the multifaceted dynamics of carbon emissions and green industrialization in Africa. Following extant literature, therefore such as Idowu et al (2023); Mirziyoyeva, et al (2022), the following functional form of the model is specfied

$$CO_2E = f(reec, recind, ind, psav, fdi) \quad 1$$

CO_2E stands for carbon emissions in (kt), reec represents renewable energy consumption, ind stands for industry value added, psav represents political stability and absence of violence, and fdi represents foreign direct investment.

Equation 1 is transformed to econometric forms as

$$logCO_2E_{it} = \beta_0 + \beta_1 logreec_{it} + \beta_2(logE_{it} * logind_{it}) + \beta_3 logind_{it} + \beta_4 logpsav_{it} + \beta_5 logfdi_{it} + \varepsilon_{it} \quad (2)$$

$\beta_0 =$ intercept of the model, β_k(k = 1, 2,…,5) represents the coefficient of the explanatory variables, i represents individual African country (1-48) and t stand for the period (2000 – 2022). ε_{it} stands for the disturbance error term. On theoretical apriori ground, the coefficient of $\beta_1$and β_2 are expected to be negative while β_3, β_4 *and* β_5 are expected to be positively related.

Estimation Techniques

Pre-Estimation Test

Test for Cross – Sectional Dependence

One challenge that arises when working with panel data is the potential presence or absence of cross-section dependence, which means that variables in one country may be influenced by shocks in other countries. Failure to assess this before conducting a Unit Root Test can lead to misleading results. Therefore, the test was conducted using the four distinct tests statistics involving the Breusch-Pagan LM test (1980), Pesaran Scaled LM test (2008), Bias-corrected LM scale test, and the Pesaran CD test. All these tests are performed under the null hypothesis that there is no presence of cross-sectional dependence. Equation 3 to 6 provide the specification for each of the test. Breusch-Pagan (1980) LM test follow

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\, \hat{p}_{ij}^2 \rightarrow \chi^2 \frac{N^2-N}{2} \quad (3)$$

$\hat{p}_{ij}^2$ represents the residual correlation coefficients obtained from the specified equation in 3.

The Pesaran (2004) LM statistics takes the form:

$$LM_s = \left(\frac{1}{N^2-N}\right)^{\frac{1}{2}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T_{ij}\hat{p}_{ij}^2 - 1\right) \rightarrow N(0.1) \quad (4)$$

Bias – corrected Scaled LM test statistics is computed as

$$LM_{BC} = \left(\frac{1}{N^2-N}\right)^{\frac{1}{2}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T_{ij}\hat{p}_{ij}^2 - 1\right) - \frac{N}{2(T-1)} \rightarrow N(0.1) \quad (5)$$

The Pesaran CD test is computed as

$$CD_p = \left(\frac{1}{N^2-N}\right)^{\frac{1}{2}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\hat{p}_{ij} \rightarrow N(0.1) \quad (6)$$

The null hypotheses posited for all of the tests are as follows:

$$H_0: \hat{p}_{ij} = cor\left(\mu_{it,}\mu_{jt}\right) = 0 \; for \; i \neq j \quad (7)$$

Test for Slope Homogeneity

Another important consideration as regard panel data is the test for slope homogeneity. Slope homogeneity needs to be conducted in panel data to assess whether the relationships between independent variables and the dependent variable are consistent across different time periods or groups, ensuring the validity of regression analysis. To mitigate potential errors arising from slope homogeneity, the test was conducted following the method outlined by Pesaran and Yamagata (2008), incorporating the computation of the Swamy test (1970) to address any form of non-uniformity in the regression coefficients across different subgroups or time periods. Equation 8 specify the Swamy equation:

$$\hat{S}_w = \sum_{i=1}^{N} (\hat{\alpha}_i - \hat{\alpha}_{WFEP})'\, X_I' \frac{M_T X_i}{\delta_i^2} (\hat{\alpha}_i - \hat{\alpha}_{WFEP}) \quad (8)$$

$\hat{\alpha}_i$ represents the Ordinary Least Square pooled estimator, $\hat{\alpha}_{WFEP}$ represents the pooled estimator weighted fixed effect while δ_i^2 represents value of the estimator. Equations 9 and 10 offer standard dispersion statistics for Equation 6 in the following manner:

$$\hat{\Delta} = N^{-1} = \left(\frac{\hat{S}_w - k}{2k}\right). \quad (9)$$

The adjusted delta coefficient statistics of equation 8 is computed as:

$$\hat{\Delta}_{adj} = \sqrt{N}\left(\frac{\frac{1}{N}\hat{S}_w - E(\tilde{q}_{it})}{var^{\frac{1}{2}}(q_{it})}\right) \quad (10)$$

Panel Unit Root Test

When confronted with the presence of cross-sectional dependence within a panel series, the conventional first-generation unit root test becomes inadequate. Consequently, we resorted to a more robust unit root test from the second generation, capable of accommodating series entangled with cross-sectional dependencies. Specifically, we applied the Cross-sectional Augmented Dickey-Fuller (CADF) test, as advocated by Im, Pesaran, and Shin (2003) (CIPS), to ascertain the stationarity properties of the variable. The CADF statistic was computed according to the following formula:

$$\Delta z_{it} = \beta_i + b_i z_{i,t-1} + c_i \bar{z}_{t-1} + d_i \Delta \bar{z}_t + e_{it} \quad (11)$$

Where$\bar{z}$ and $\Delta\bar{z}$ represents the average of the cross-section test at levels and the first difference at time t across the series. Pesaran (2007) CADF follows.

$$CADF_i = t_i(N,T) = \frac{\Delta y_i' \bar{M}_w y_{i,-1}}{\hat{\sigma}_i (y_{i,-1}' \bar{M}_w y_{i.-1})^{\frac{1}{2}}} \quad (12)$$

The CIPS is generated from equation 11 as:

$$CIPS = N^{-1} \sum_{i=1}^{N} CADF_i \quad (13)$$

Cointegration Test

Given the observed cross-sectional dependence in the variables, the conventional panel cointegration test is inadequate for analysis. Consequently, we conducted the Westerlund (2007) panel cointegration test to investigate the potential presence of a long-run relationship among these variables.

Under the null hypothesis, we assessed whether the variables exhibited cointegration through two group-mean and two panel tests, while considering the alternative hypothesis that cointegration indeed exists. We present the computations of the Westerlund (2007) test within the framework of the error correction model as represented by the following:

$$\Delta z_{it} = \delta_i' d_t + b_i\left(z_{i,t-1} - \beta_i' g_{i,t-1}\right) + \sum_{j=1}^{pi} b_{ij}\Delta z_{i,t-j} + \sum_{qi}^{pi} \gamma_{ij}\Delta g_{i,t-j} + \varepsilon_{it} \qquad (14)$$

d_t , p_i, and q_i represent the deterministic components, lag lengths and the lead orders that differ among the cross section of individual. The Westerlund (2007) cointegration analysis includes two group-mean test statistics, denoted as G-tau and G-alpha, along with two panel test statistics, labeled as P-tau and P-alpha:

$$G_{-tau} = \frac{1}{N}\sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \qquad (15)$$

and

$$G_{-alpha} = \frac{1}{N}\sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \qquad (16)$$

$\hat{\alpha}_i$ here stand for the estimate of the error correction while the standard error for the estimate is represented by $SE(\hat{\alpha}_i)$.

The panel statistics are formulated as follows:

$$P_\tau = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \qquad (17)$$

also

$$P_\alpha = T\hat{\alpha} \qquad (18)$$

Results and Discussions

Descriptive Statistics

The descriptive statistics reveal substantial disparities across the variables studied. For CO_2 emissions, the mean value of 23,106.46 kt is much higher than the median of 3,635.3 kt, highlighting the presence of outliers in the dataset. The range spans from as low as 53.5 kt to as high as 448,298.1 kt, with a very large standard deviation of 64,739.96, pointing to extreme variability among countries. The distribution is highly right-skewed (skewness = 4.553) and exhibits heavy tails (kurtosis = 25.368), indicating that while most countries emit relatively low levels of CO_2, a few highly industrialized economies account for disproportionately large emissions. By contrast, renewable energy consumption (reec) averages 61.57% of total energy use, with a median of 72.81%, showing that many African countries rely heavily on renewables. The relatively low standard deviation (28.73) indicates limited variation across observations, while the negative skewness (-0.68) suggests that more countries cluster toward higher levels of renewable energy adoption.

For industrial value added per worker, the mean stands at 17,551.5 US dollars, while the median is much lower at 7,186.55 US dollars, suggesting wide differences in productivity across countries. The high standard deviation of 35,552.49 confirms this variability, which likely reflects disparities in industrial capacity and technological development. The positive skewness of 3.92 indicates that while most countries have relatively low industrial productivity, a small number record extremely high values that raise the average. Turning to political stability (psav), the average score of -0.547 and the median of -0.427 suggest that political instability and risks of violence or terrorism are widespread across the sample. Although the standard deviation of 0.866 shows some variability, the slight negative skewness (-0.13) suggests that more countries tend to score closer to relatively less negative values, even though the overall regional context still reflects fragile political environments.

Finally, foreign direct investment (FDI) as a share of GDP averages 4.26%, but the median is much lower at 2.46%, implying that most countries attract modest levels of FDI while a few receive disproportionately high inflows. The standard deviation of 8.16% reveals considerable variation across countries, while the strong right-skewness (5.56) indicates that only a handful of economies capture significantly larger FDI relative to their GDP. Taken together, the descriptive results highlight the uneven nature of economic development in Africa: CO2 emissions and industrial productivity are concentrated in a few economies, renewable energy reliance is broadly high across the continent, political stability remains fragile on average, and FDI inflows are skewed toward a small group of countries.

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Table 1: Descriptive Statistics

	CO_2E	reec	Ind	psav	fdi
Mean	23106.46	61.568	17551.5	-0.547	4.257
Median	3635.3	72.810	7186.6	-0.427	2.460
Maximum	448298.1	98.340	242771.5	1.579	103.337
Minimum	53.5	0.060	194.0	-2.699	-32.729
Std. Dev.	64739.96	28.731	35552.5	0.866	8.156
Skewness	4.553	-0.682	3.9	-0.130	5.564
Kurtosis	25.368	2.114	18.9	2.532	52.091
Jarque-Bera	26830.31	121.817	14429.4	13.191	116553.4
Probability	0.000	0.000	0.000	0.001	0.000
Observations	1104	1104	1104	1104	1104

Source: Authour computation from WDI (2022)

Cross Sectional Dependence Test

The results pertaining to cross-sectional dependency are displayed in Table 2. In each instance, the findings strongly support the rejection of the null hypothesis that there is no cross-sectional dependence, with statistical significance at 5% levels. This indicate that common factors or interactions among these African countries influence their economic performance. Similarly, the test statistics observed for all delta tests and the adjusted delta tests, as presented in Table 3, substantiate the rejection of the hypothesis of zero slope homogeneity at the 5% significance level. The null hypothesis of uniform slopes across entities across the African region is rejected at the 5% significance level, indicating that there are significant differences in the relationships between variables across different selected countries. This affirms the existence of slope heterogeneity within the dataset.

Table 2. Test for Cross-Sectional Dependence Result

	Test Statistics and probability					
	CO_2E	Reec	recind	ind	psav	fdi
Breusch - Pagan LM	13933.01*	9579.568*	8682.602*	9458.829*	5148.962*	2488.022*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pesaran Scaled LM	268.583*	176.927*	158.043*	174.385*	83.646*	27.623*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bias-Corrected Scaled LM	267.493*	175.836*	156.952*	173.294*	82.555*	26.532*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pesaran CD	88.526*	54.831*	1.435	4.919**	-0.191*	7.820*
	(0.000)	(0.000)	(0.153)	(0.000)	(0.848)	(0.000)

*Note: * Show evidence of rejecting the null hypothesis of no cross-sectional dependence at the 5% significance level*

Table 3. Test for Slope homogeneity Result

Delta Tests	Test Statistics and Prob.					
	CO_2E	reec	recind	ind	psav	fdi
Delta Tilde	6.518*	7.762*	4.654*	4.786*	7.765*	3.453*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Delta Tilde adjusted	7.897*	8.342*	4.876*	5.321*	8.809*	3.486*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: The probability values are enclosed in parentheses, and asterisks (*) indicate statistical significance at the 5% level.

Westerlund Cointegration Test

To examine the presence of a long-term relationship between green industrialization and CO_2 emissions in Africa, we employed the Westerlund cointegration test. The estimated statistics, including g-tau, g-alpha, p-tau, and p-alpha, all demonstrate strong statistical significance. The null hypotheses was rejected concluding that green industrialization and CO_2 emissions in Africa has a long run connection. This implies that there is indeed a meaningful and sustained long-term connection between the two variables, highlighting the significant influence of green industrialization practices on CO_2 emissions in the African context.

Table 4. Westerlund (2007) test for cointegration

Statistics	Coefficient	ρ -value
g-tau	-5.712**	0.000
g-alpha	-4.184**	0.002
p-tau	-3.902**	0.013
p-alpha	-2.763**	0.010

Note: ** denotes significant at 5%

CADF and CIPS Unit Root Test

Table 5 summarizes the findings of the unit root analyses. From the CIPS results, only Co_2E, fdi and recind were stationary at levels, however, ind, psav and reec became stationary at first differencing. On the other hand, the CADF result show that the series were stationary at levels with the exception of reec. However, reec also achieved stationarity after first differencing. Thus, none of the variables was integrated beyond first difference I(1).

Table 5. Unit Root Tests

	Level		First Difference	
Variable	CIPS	CADF	CIPS	CADF
CO_2E	-2.338	-3.024***	-4.404	-4.964***
		(0.001)		(0.000)
lfdi	-2.737	-1.537*	-5.324	-6.112***
		(0.062)		(0.000)
recind	-2.812	-1.955**	-4.567	-7.243***
		(0.025)		(0.000)
ind	-1.485	3.867	-3.857	-1.513*
		(1.000)		(0.065)
psav	-2.217	-3.235**	-4.834	-8.147***
		(0.010)		(0.000)
reec	-1.679	-0.568	-4.028	-3.846***
		(0.285)		(0.000)

Note: *** symbol denotes significance at the 1% level, ** symbol signifies significance at the 5% level, while * denotes significance at the 10% level

Empirical Result from Augmented Mean Group(AMG), and Common Correlated Effect Mean Group (CCEMG)

The study employed second-generation panel regression techniques—AMG, CCEMG, and MMQR—to analyze the long-run impact of green industrialization and control variables on CO2 emissions in Africa, accounting for cross-sectional dependence and slope heterogeneity. Results consistently showed that renewable energy consumption (reec), used as a proxy for green industrialization, significantly and negatively affects CO2 emissions. Specifically, a 1% increase in reec reduces emissions by between 0.918% and 3.347%, confirming the role of renewables in mitigating environmental degradation. This outcome aligns with the environmental Kuznets curve, which suggests that as economies grow, they adopt cleaner technologies and more efficient production methods. The results support earlier findings by Idowu et al. (2023), Lei et al. (2022), and

Yu-Ke et al. (2023), but contrast with studies such as Adebayo et al. (2022) and Bouyghrissi et al. (2021).

Further analysis revealed an intriguing interactive effect of renewable energy consumption on CO_2 emissions. While the AMG and CCEMG methods showed limited significance, the MMQR results demonstrated a strong and significant reduction at higher quantiles of CO_2 distribution. Specifically, a 1% increase in renewable energy consumption's interactive effect reduced emissions by as much as 1.716% at the 95% quantile. This highlights that renewable energy plays a more substantial role in curbing emissions in high-emission contexts. In contrast, industrial value added exhibited a positive and significant relationship with emissions. A 1% increase in industrial value added raised emissions between 0.087% and 0.104%, with a much larger increase of 0.584% at the 95% quantile. This underscores the energy-intensive nature of industrial activities in Africa and reflects the dependence of manufacturing processes on fossil fuels.

The results also pointed to the significant roles of political instability and foreign direct investment (FDI) in shaping CO_2 emissions. Political instability and violence were found to increase emissions, with a 1% deterioration in political stability leading to a rise of between 0.165% and 0.280%, depending on the method of estimation. This suggests that unstable political environments discourage renewable energy investments, thereby prolonging reliance on polluting energy sources. Similarly, FDI showed a positive and significant relationship with emissions, where a 1% increase in FDI raised CO_2 emissions by between 0.083% and 0.125%, with an even stronger effect of 1.113% at the 95% quantile. This outcome reflects the fact that FDI in Africa is often concentrated in fossil-fuel-dependent sectors such as oil, gas, and heavy manufacturing, which continue to drive emissions upward. Collectively, these findings highlight the dual challenge of promoting industrialization and investment while ensuring that growth remains environmentally sustainable.

Table 7. AMG, CCEMG and MMQR Estimates

	AMG Estimate		CCEMG Estimate		MMQR Estimate (95% quantile)	
	Coeff.	ρ value	Coeff.	ρ value	Coeff.	ρ value
Lreec	-3.296*	0.000	-3.347*	0.000	-.918*	0.006
lrecind	-0.058	0.627	-0.752	0.529	-1.716*	0.020
Lind	0.104	0.042	0.087*	0.042	0.584*	0.029
Lpsav	0.170*	0.017	0.165*	0.017	0.280*	0.021
Lfdi	0.083*	0.320	0.125*	0.047	1.113*	0.017

Note: *denotes significant at 5%

Conclusion and Policy Recommendations

This study investigates the role of green industrialization in reducing carbon emissions in Africa for the period covering 2000 to 2022. Advanced econometric methods, including Augmented Mean Group, Common Correlated Effect Mean Group, and Method of Moment Quantile Regression along with the Dumitrescu and Hurlin causality test causality test was used. The conclusion reached are as follows: first, renewable energy consumption impacted negatively and significant on CO_2 emissions in Africa while foreign direct investment, industrialization and absence of political violence increases the intensity of CO2 emission in Nigeria. Also, a bidirectional causality was found between both. Consequently, it is imperative for African countries to embrace green industrialization as a pivotal strategy for curbing CO_2 emissions and promoting sustainable industrial development. Consequently, African governments need to prioritize investments in renewable energy infrastructure, enhance regulatory frameworks to incentivize green technologies, and foster international cooperation for knowledge and resource sharing. These measures no doubt will expedite the transition toward sustainable green industrialization, that will ultimately contribute to a substantial reduction in carbon emission and advanced Africa's commitment to a greener and more sustainable future.

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