Renewable Energy Consumption and Carbon Emissions in Sub-Saharan Africa. The Moderating Role of Institutional Quality

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ABSTRACT

This paper empirically investigates the effect of renewable energy consumption, institutional quality, and their interaction on carbon emissions in the Sub-Saharan Africa region, while controlling for foreign direct investment, industrialization, and population growth. The study analyzed a balanced panel of 839 country-year observations from 24 countries covering the period 2000–2023. A fixed effects model was employed to examine the relationships and test the moderating role of institutional quality. Results indicated that renewable energy consumption had a significant negative relationship with carbon emissions, reinforcing its role in mitigating environmental degradation. Institutional quality also demonstrated a strong negative relationship with emissions, underscoring the role of governance in environmental performance. Importantly, the interaction between renewable energy and institutional quality further enhanced the negative effect on carbon emissions, indicating that the effectiveness of renewable energy initiatives is significantly enhanced in the presence of strong institutions. The findings of this study contribute to the growing empirical literature on the relationship between renewable energy consumption, institutional quality, and environmental sustainability in Sub-Saharan Africa. Moreover, they offer critical policy insights for governments, development partners, and energy stakeholders. Given the significant negative relationship between renewable energy consumption and carbon emissions, policymakers should intensify efforts to expand renewable energy infrastructure and adoption. The amplifying effect of institutional quality highlights the urgency of governance reforms to support enforcement, transparency, and accountability in energy transitions.

Key words: Renewable energy consumption, institutional quality, sub-Saharan Africa, carbon emissions

INTRODUCTION

The demand for economic and environmental sustainability has recently necessitated investigations on the effects of renewable energy usage on both economic and environmental sustainability. The issue has been a subject of discourse among policymakers and researchers. In 2015, both 'The Paris Agreement' and the Agenda for Sustainable Development-2030 were ratified as integral components of a strategic approach to energy access and climate change mitigation (UNFCC, 2015; United Nations, 2015). In the agreed pact, global economies committed to uniting to eradicate poverty in all aspects of life. Furthermore, the global economies consented to collaborate synergistically to comprehensively promote sustainable development and address the challenge of climate change integrally. Nevertheless, a vision of a clean energy system is the sole method to attain the articulated objectives of both pledges, essential for conquering energy poverty and ensuring environmental sustainability.

The SSA nations, in accordance with the 2015 Paris Climate Change Conference and subsequent meetings, have recently committed to and adopted the objectives of the Renewable Energy Initiative (REI) for the year 2030.

This REI program establishes unorthodox objectives for the economy of the regional bloc. The primary objective is to ensure that by 2030, the share of renewable energy in the consumption mix reaches a target of 15%. The primary concerns regarding the realization of this objective include transportation targets for various sectors, as well as issues related to electricity and temperature regulation. Additional elements encompass the integration of various renewable technologies through structured energy policy frameworks, alongside corporate utilization targets to establish collaborative support systems and initiatives among the nations within the regional bloc.

Researchers have recently highlighted the role of institutions, noting that fossil fuel potential and energy use are not the exclusive determinants of environmental degradation; rather, the quality of institutions within society also plays a significant role (Uzar, 2020). Ndulu & O'Connell (1999) indicate that a significant research initiative conducted by the AERC highlighted the substantial emphasis placed on institutions in elucidating the growth of African economies. A substantial body of literature has empirically examined the effects of population, economic growth, and energy consumption on carbon emissions within the realms of energy and environmental economics; however, the influence of institutions on carbon emissions remains a relatively underexplored topic (Adegboye et al, 2020).

Certain academics assert that the significance of institutional variables on the environment must not be overlooked, since institutions pertain to the rules and norms governing conduct that shape repetitive human interactions (Vatn, 2007). Institutional factors, including corruption, political stability, governmental regulation, the rule of law, and governmental efficacy, significantly influence environmental policies and strategies aimed at reducing carbon emissions (Muhammad & Long, 2021). According to Bhattacharya, Churchill, and Paramati (2017), institutions that uphold property rights and facilitate voluntary exchange empower the government to implement preferred environmental policies. In other words, environmental activities aimed at reducing carbon emissions may be compromised if institutions lack functionality and efficiency. Although institutions serve as indicators and precursors to various developmental outcomes, it is crucial to understand their influence on carbon emissions.

The research employed a fixed effects framework to estimate a dynamic cross-sectional environmental model, aiming to assess the consistency and robustness of the results. The study analyzes a cross-section of 23 chosen Sub-Saharan African (SSA) nations from 2000 to 2023. This research utilizes a panel dataset to investigate the moderating effect of institutional quality on the link between renewable energy consumption and carbon emissions. The document is structured as follows: Section 2 presents a review of pertinent literature review material subsequent to the introduction in Section 1. Section 3 delineates the approach, encompassing verifiable models; Section 4 discusses the empirical results; and Section 5 concludes the article with policy recommendations based on the findings.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Renewable energy consumption and economic growth

Abbasi, *et al.,* (2021) reported that Thailand's Nationally Determined Contribution (NDC) aimed to reduce CO2 emissions by 20-25%. In order to successfully reach the long-term goal of the Paris Agreement, which is to keep global temperature rise well below 2 °C, it is imperative to take bold and proactive measures for reducing greenhouse gas emissions beyond the year 2030. The study investigated the influence of the rate at which energy is depleted, the consumption of renewable energy, the rate at which non-renewable energy is depleted, and the GDP on CO2 emissions in Thailand from 1980 to 2018, considering their significance. The study employed a novel dynamic ARDL simulations model [1] and conducted a frequency domain causality (FDC) test. The empirical results showed that the rate of depletion had a substantial negative effect on CO2 emissions, both in the long term and the short term. In addition, our findings indicated that renewable energy had a significant and negative effect on CO2 emissions in the short term. Nevertheless, the rate at which non-renewable energy is being used up and the gross domestic product (GDP) have been found to have a significant and positive impact on carbon dioxide (CO2) emissions, both in the short term and in the long term, according to statistical analysis. The FDC test has verified the presence of causality in the short, medium, and long term between DR, RE, DRNRE, and CO2 emission.

In their study, Yuping, *et al.,* (2021) aimed to assess the impact of globalization, renewable energy consumption, non-renewable energy consumption, and economic growth on carbon dioxide emissions in Argentina from 1970 to 2018. The econometric methodology employed in this study utilized robust methods to address structural break issues in the data. The Maki cointegration analysis, which accounted for multiple structural breaks, identified significant long-term relationships between carbon-dioxide emissions, renewable and non-renewable energy consumption, globalization, and economic growth. The Autoregressive Distributed Lag analysis of models revealed that renewable energy consumption and globalization have a negative impact on emissions, while non-renewable energy consumption has a positive impact on emissions, both in the short- and long-term. In addition, it was discovered that the combination of globalization and renewable energy consumption led to a decrease in emissions. Conversely, the combination of globalization and non-renewable energy consumption led to an increase in emissions, but only in the long-term.

Saidi and Omri (2020) conducted a study to analyze the effects of renewable and nuclear energy consumption on CO2 emissions in 15 OECD countries from 1990 to 2018. They used two estimation methods, namely the Fully Modified OLS (FMOLS) and the vector error correction model approach (VECM), to examine both the short-term and long-term impacts. The findings from the FMOLS analysis indicated that investment in nuclear energy led to a decrease in CO2 emissions in several countries including Canada, Netherlands, Japan, Switzerland, Czech Republic, and UK. On the other hand, investment in renewable energy resulted in a decrease in CO2 emissions in Belgium, Canada, France, Germany, Sweden, UK, US, Japan, Switzerland, Finland, and Czech Republic, but it led to an increase in CO2 emissions in Netherlands and South Korea. Furthermore, both nuclear and renewable energy consumption contributed to a reduction in carbon emissions based on the panel estimations. Furthermore, the findings from the VECM approach demonstrated that nuclear and renewable energies have a long-term effect in decreasing CO2 emissions.

Chen, *et al.,* (2022) conducted a comprehensive analysis of the relationship between energy and economic growth and carbon dioxide (CO2) emissions per capita in response to growing concerns about climate change. This study contributed to the existing body of literature on the subject. Most of the previous studies used different linear panel estimation methods without considering the possible nonlinear impacts of energy and income on per capita CO2 emissions. In order to address this deficiency, this research employed panel data encompassing 97 countries from 1995 to 2015. It investigated the non-linear effects of renewable and non-renewable energy consumption, as well as economic growth, on per capita CO2 emissions. This investigation utilized a dynamic panel threshold model that is resilient to cross-section dependence. The results of our study showed that there is a negative and significant relationship between the increase in per capita renewable energy consumption and the growth of per capita CO2 emissions, but only when countries exceed a certain threshold of renewable energy consumption.

In their study, Jamil, *et al.,* (2022) aimed to conduct a comparative analysis of CO2 emissions, renewable energy usage, trade openness, gross domestic product (GDP), financial development (FD), and remittance in a specific group of G-20 countries. The study utilized fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) models to estimate annual data from 1990 to 2019. The LM tests identified the presence of cross-section dependability, while the stationarity of the variables was assessed using the Levin-Lin-Chu and Im-Pesaran-Shin tests, as well as Hansen's Covariate-Augmented Dickey Fuller (CADF) test, considering the existence of cross-section dependency. The panel unit root tests indicated that all variables achieved stationarity after being transformed into their first differences. The Panel Cointegration and Wester-Lund test investigated whether there is a long-term equilibrium relationship among specific variables in the G-20 countries. The study's results revealed a substantial and adverse correlation between renewable energy and CO2 emissions. Two models demonstrated a positive correlation between the economic growth of specific G-20 countries and their CO2 emissions. Moreover, the results revealed that the financial development coefficient has a positive and significant effect on CO2 emissions. The remittances had a substantial and beneficial impact on CO2 emissions, while trade openness had a negligible effect on CO2 emissions across the two models.

Namahoro, *et al.,* (2021) conducted a study to investigate the relationship between energy consumption, economic growth, and CO2 emissions at both regional and global levels, taking into account different levels of development. Only a small number of studies conducted at the African level failed to consider the variations in regions and income levels among the countries included in the research. This study conducted an empirical

analysis to investigate the long-term effects of energy intensity, renewable energy consumption, and economic growth on CO2 emissions in 50 African countries across different regions and income levels from 1980 to 2018. State-of-the-art panel estimators, causality tests, and analysis of impulse response and variance decomposition were utilized. The panel estimators' findings indicated that the consumption of renewable energy significantly helped to reduce CO2 emissions. However, energy intensity was found to increase emissions across different regions and income levels, including at the African level. Economic growth had a detrimental negative impact on CO2 emissions at the African level, although the effect varied across regions and income levels. The causality test has confirmed the presence of bi-directional causations between CO2 emissions and its determinants in various regions and income levels in Africa.

Dong, *et al.,* (2020) argue that previous studies often overlooked the substantial disparity in the relationship between emissions and renewable energy across countries with varying income levels. An empirical study was conducted to examine whether the impact of renewable energy consumption on carbon dioxide (CO2) emissions varies among countries with different income levels. The study analyzed a global panel of 120 countries and divided them into four subpanels based on income levels. The data covered the period from 1995 to 2015. By taking into account the possible cross-sectional dependence and variation in slopes, a range of econometric methods that accommodate cross-sectional dependence and slope heterogeneity are employed. Both the global panel and all four subpanels exhibit confirmed cross-sectional dependence and slope heterogeneity. The validity of the environmental Kuznets curve (EKC) hypothesis was observed only in the global panel, high-income subpanel, and upper-middle-income subpanel. While renewable energy consumption does have a negative impact on CO2 emissions, its influence is not substantial.

Saidi and Omri (2020) did a study to analyze the impact of renewable energy on economic growth and carbon emissions in 15 major renewable energy-consuming countries. This will be done using fully modified ordinary least square (FMOLS) and vector error correction model (VECM) estimation techniques. The FMOLS technique results demonstrated the effectiveness of renewable energy in enhancing economic growth and decreasing carbon emissions. The VECM Granger causality test revealed bidirectional causality between economic growth and renewable energy in both short- and long-run for both estimated functions, confirming the feedback hypothesis. Additionally, it shows there is no causal connection between the emissions of carbon dioxide and renewable energy in the long-run, but there is a bidirectional causal connection between the two variables in the short-run.

Adams & Acheampong (2019) did a study to investigate how democracy and renewable energy affect carbon emissions in 46 sub-Saharan African nations utilizing imbalanced data from 1980 to 2015. The study utilized an instrumental variable generalized method of moments to determine that democracy and renewable energy had an improving impact on carbon emissions. Foreign direct investment, trade openness, population, and economic growth were the factors driving carbon emissions in sub-Saharan Africa. Accounting for democracy leads to a decrease in carbon emissions despite economic development. No evidence supporting the existence of the Environmental Kuznets curve was discovered. The studies also showed that the influence of urbanization on carbon emissions is uncertain.

According to Dogan and Seker (2016), recent decades have seen a significant rise in carbon dioxide (CO2) emissions, leading to several research in the field of energy-growth-environment that aim to pinpoint the factors influencing CO2 emissions. The study acknowledged a significant critique about the choice of panel estimation methods in the current investigations. Most studies utilized panel methods that overlook cross-sectional dependency, despite the high probability of heterogeneity and cross-sectional dependence among nations in the panel. Most current studies analyzed overall energy use and do not distinguish the environmental implications of energy consumption from different sources. This empirical study examined how real income, renewable energy consumption, non-renewable energy consumption, trade openness, and financial development impact CO2 emissions in the EKC model for top countries in the Renewable Energy Country Attractiveness Index. The study uses heterogeneous panel estimation techniques with cross-section dependence to address gaps in the literature. After doing the CADF and CIPS unit root tests, the study sawed that the variables achieved stationarity in their initial differences. Additionally, the LM bootstrap cointegration test indicated that the variables are cointegrated. FMOLS and DOLS analyses reveal that higher levels of renewable energy consumption, trade openness, and financial development lead to a decrease in carbon emissions. Conversely, an

increase in non-renewable energy consumption is associated with higher emissions. The EKC hypothesis is confirmed for the leading renewable energy countries.

Jin & Kim (2018) studied the factors influencing carbon emissions by examining energy consumption statistics from 30 nations that utilize nuclear energy between 1990 and 2014. Renewable energy and nuclear energy consumption are considered as factors, while real coal price and real GDP are included as additional variables. Panel cointegration analysis and Granger causality tests are performed to explore the link between the variables. The panel cointegration test indicated the presence of a long-term equilibrium link between carbon emissions, renewable energy consumption, and nuclear energy consumption. The long-term cointegrating vector and Granger causality tests showed that nuclear energy does not aid in reducing carbon emissions, unlike renewable energy.

A study by Nguyen and Kakinaka (2019) analyzed the correlation between renewable energy usage and carbon emissions in 107 countries from 1990 to 2013, using panel cointegration analysis to consider the development stage. The data demonstrated considerable disparities between the low- and high-income country groupings. Renewable energy usage in low-income nations had both a positive and negative correlation with carbon emissions and output, respectively. In high-income countries, there was a mixed relationship between renewable energy usage and carbon emissions as well as output.

Salem *et al.,* (2021) choose the top ten nations with large carbon emissions to analyze the trends in renewable energy usage from 1991 to 2018. Developed renewable energy companies were a gradual process that does not happen quickly. Additionally, it involved a period of infrastructure building that could lead to a temporary increase in CO2 emissions. Renewable energy consumption, including Wind, Solar, and Hydropower, were utilized to analyze the non-linear relationship with CO2 and its variations. The empirical findings obtained by a pooled mean group (PMG) approach suggest that renewable energy consumption and hydropower exhibit an inverted U-shaped pattern, whereas wind and solar energy consumption display a U-shaped pattern.

H1. Renewable energy consumption has a significant effect on Carbon emissions in SSA

Institutional quality and carbon emissions

In their study, Bakhsh, et al., (2021) investigated how institutional quality and technological innovation influence the relationship between foreign direct investment (FDI) inflows and four CO2 emissions indicators in 40 Asian countries from 1996 to 2016. They employed the generalized method of moment (GMM) estimation to analyze the data. Our empirical findings indicated that FDI inflows have a positive effect on CO2 emissions, particularly in the context of non-interactive regression. However, we have also determined that the role of institutional quality and technological innovation is essential in influencing the relationship between FDI and CO2 emissions. Specifically, the interaction between institutional quality measures and FDI inflows has been found to significantly decrease the level of CO2 emissions. Moreover, there is a notable moderating impact of technological innovation on the relationship between foreign direct investment (FDI) and carbon dioxide (CO2) emissions.

In their study, Khan and Rana (2021) investigated the impact of trade, institutional quality, and their interactions on carbon dioxide emissions in a panel sample of 40 Sub-Saharan African countries. They employed the system generalized method of moments to analyze the data. Our findings indicated that institutional reforms have a clear and undeniable positive impact on the environment. Conversely, the effects of trade on the environment are contingent upon the institutional framework of a nation. To be more precise, trade openness has a detrimental effect on the environment in countries that have poor institutional quality, while it has a positive impact on the environment in countries with high institutional quality. This implies that countries with low institutional quality must undergo institutional reforms in order to fully realize the positive impact of trade on their environment.

Khan and Rana (2021) While Asian economies have experienced significant economic growth in recent decades, the increasing levels of pollution emissions are causing policymakers to question the long-term sustainability of this growth. This study examined the cause-and-effect connection between economic growth, energy usage, openness to trade, development of the financial sector, foreign direct investment, government spending,

institutional quality, and pollution emissions in 41 Asian economies from 1996 to 2015. In addition, we conduct separate tests to assess the influence of political and economic institutions on pollution emissions in the economies included in our sample. The results obtained from our analysis using the panel cointegration method and panel vector error correction models (VECM) confirmed the existence of a cointegration relationship among all the variables we have selected. Although economic development, energy consumption, trade openness, and foreign direct investment contribute to environmental degradation, financial development and improved economic institutions assist the selected countries in reducing their pollution emissions. Furthermore, improved economic and political institutions play a role in mitigating the negative effects of income, trade openness, and foreign direct investment (FDI) on pollution emissions. According to the VECM model, per capita GDP is the sole variable that has a causal impact on pollution emissions in all of the models. The causal effect is significant only in a few cases for all the other variables.

In their study, Haldar and Sethi (2021) examined how the quality of institutions affects the relationship between energy consumption and CO2 emissions in 39 developing countries from 1995 to 2017. They also considered other factors such as trade, capital formation, foreign direct investment (FDI), financial development, and population. We employed various econometric techniques, namely mean group (MG), augmented mean group (AMG), common correlated effects mean group (CCEMG) estimator, dynamic system GMM, panel grouped-mean FMOLS, and panel quantile regression, to analyze the empirical results. Through various estimation techniques, we have discovered that the quality of institutions plays a moderating role in energy consumption and enhances its effectiveness in reducing carbon emissions. The joint impact of institutional quality and energy consumption by sector on emissions is substantial and adverse. Our research also validated the hypothesis of the Environmental Kuznets curve (EKC) when considering the influence of institutional quality. Renewable energy usage has been observed to substantially decrease emissions over an extended period of time.

Jahanger, et al., (2023) Although developing economies have achieved economic success, the majority of them have not yet achieved environmental sustainability. However, if these economies fail to maintain the quality of the natural environment, they will also fail to sustain their trade and industry growth. The primary objective of this study was to investigate the impact of natural resources and institutional quality on carbon emissions throughout the process of globalization. This was achieved by employing two-stage least square and panel threshold methods on a global panel consisting of 73 countries that were developing from 1990 to 2018. This study also applied these empirical models to three sub-panel regions: Asia, Africa, and Latin America. The study's findings indicated that natural resources, globalization, institutional quality, and human capital have had a detrimental effect on carbon dioxide emissions. On the other hand, foreign investment and consumption of energy have the potential to increase emission levels. The panel threshold test revealed that economies in developing nations with natural resources scoring beneath the threshold of 3.0315 points are likely to experience an increase in environmental pollution. This study emphasized the moderating impact of institutional quality and natural resources on carbon emissions. The findings of the other study indicated that both the environmental Kuznets curve and pollution haven hypothesis were present in all countries.

In a study conducted by Yuan, et al., (2022), China's economy is under increasing pressure to decrease carbon dioxide (CO2) emissions. This study examined the influence of green innovation and institutional quality on CO2 emissions, and analyzed the moderating influence of institutional quality. The findings indicated that: (1) Green innovation greatly decreased the amount of CO2 emissions. The presence of high institutional quality had an adverse impact on the correlation between green innovation and CO2 emissions. Specifically, when institutional quality is elevated, green innovation exhibited a more pronounced decrease in CO2 emissions. (2) Green innovation greatly decreased carbon dioxide (CO2) emissions in both the eastern and western regions. Furthermore, as the quality of institutions improved, there is an increase in the reduction of CO2 emissions through green innovation in the western region. The impact of green innovation on reducing CO2 emissions was more significant during the period of 2013-2017 compared to 2005-2012.

In their study, Dada and Ajide (2021) investigated the influence of institutional quality on the relationship between the shadow economy and environmental pollution in Nigeria from 1984 to 2018. In addition, the study also identified a particular form of institutional quality which reduced the size of the shadow economy and mitigated environmental pollution. The shadow economy was quantified as a proportion of the gross domestic product (GDP) through the utilization of the currency demand approach, while pollution to the environment is

represented by the per capita emission of carbon dioxide (CO2). The estimation technique employed was Autoregressive Distributed Lag (ARDL). The study's findings indicated that the shadow economy has a notable and positive impact on environmental pollution, both in the short and long term. Conversely, the quality of institutions was found to have an adverse influence on environmental pollution. This study demonstrated that the presence of a shadow economy has a negative impact on environmental quality, while the quality of institutions helps to reduce environmental pollution. In the long term, the correlation between the interacting term of shadow economy and institutional quality had a negative impact on environmental pollution, although this impact was not statistically significant.

Boussaidi and Hakimi (2025, January) aimed to examine the potential advantages of a more inclusive financial system for both economic growth and the environment. Additionally, it examined the moderating influence of institutional quality (IQ) on the relationship between growth and the environment. The study utilized a dataset consisting of 12 countries in the Middle East and North Africa (MENA) region, covering the period from 2004 to 2021. The analysis employed the seemingly unrelated regression (SUR) model. The results suggested that the presence of financial inclusion (FI) had a notable impact on the magnitude of CO2 emissions. Therefore, the presence of a more comprehensive financial system has had a negative impact on the environmental conditions in the MENA region. Nevertheless, FI does not have a substantial impact on the rate of growth. Moreover, our research revealed that the correlation between FI and IQ positively influenced development and enhanced the overall condition of the surroundings. The observed impact is more evident when the variable being measured is the quality of the environment rather than growth.

H2. Institutional quality has a significant effect on the relationship between renewable energy consumption and Carbon emissions in SSA

RESEARCH METHODOLOGY

Sample size and data

The target population for this study was all countries in Sub-Saharan Africa. The selection of the countries was based on the criteria of whether the country was an independent country within the study period, which is from 2000 – 2023, and the availability of complete data that captured all variables used in this study. The dataset used for this study is secondary data extracted from the World Bank database and countries' specific Bureau of Statistics websites. Our final sample was 552 country-year observations representing 24 countries.

Measurement of variables

This section addresses the measurement of the research variables. Carbon emission is the dependent variable, while renewable energy consumption and financial development are the independent variables, and institutional quality is used as a moderating variable. The study includes control variables such as foreign direct investment, population, and industrialisation. Comprehensive definitions and measurements of all research variables are provided in Table 1.

Table 1: Measurement of variables

Variable	Category	Operationalization	Acronym
CO2 Emissions	Dependent Variable	The unit of measurement is kt (kiloton) (Boden, Marland & Andres, 2013).	CE
Renewable Energy Consumption	Independent variable	Measured as share of renewable energy (Kilowatt-Hours, kWh) in total final energy consumption (World bank, 2022).	REC
Institutional Quality	Moderator variable	Composite index of political stability, control of corruption, regulatory quality, the rule of law, voice and accountability, and government effectiveneness (Kaufmann *et al*., 2009; Langbein	IQ

		and Knack, 2010)	
Foreign Direct Investment	Control variable	FDI is the measure of investment inflows (Pattayat, 2016)	FDI
Population	Control Variable	The population of a given area is the number of people usually living in that country (Gu, Andreev & Dupre, 2021)	POP
Industrialization	Control variable	According to Anchi, Aboubakary, and Edoh (2023), the amount of net output produced by the manufacturing sector in the economy	IND

Source, Researcher (2025)

Regression models

The following regression equations were adopted to test the proposed hypotheses:

Model 1: testing the effect of control variables on carbon emissions.

$$CE_{it} = \beta_0 + \beta_1 FDI_{it} + \beta_2 POP_{it} + \beta_3 IND_{it} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Model 2: testing the effect of renewable energy consumption and financial development on carbon emissions.

$$CE_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 FDI_{it} + \beta_3 POP_{it} + \beta_4 IND_{it} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Model 3: testing the effect of institutional quality on carbon emissions.

$$CE_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 IQ_{it} + \beta_{(3-5)} Controls + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Model 4: Testing the interaction between renewable energy consumption and institutional quality.

$$CE_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 IQ_{it} + \beta_3 RE * IQ_{it} + \beta_{(4-6)} Controls + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

EMPIRICAL FINDINGS AND DISCUSSION

Diagnostic tests

Hausman test (p=0.000) for the choice between fixed effect and random effect model indicated that the fixed effect model was the most appropriate model for the study. Multicollinearity test results indicated that the model did not suffer from multicollinearity, Breusch-Pagan test indicated that the model did not suffer from heteroscedasticity and Breusch-Godfrey test results also indicated that the model did not suffer from autocorrelation. These results confirm the model's robustness and reliability.

Descriptive statistics

Table 2 shows the descriptive statistics of seven key variables over different observation counts (Obs) across different countries or regions. Carbon emissions have mean of 47,327.03 metric tons and standard deviation of 157,595.7, which suggests large differences in carbon emissions among countries. Sao Tome and Principe recorded the lowest carbon emission in Sub-Saharan Africa, while DRC emitted the highest, and the minimum value of 53.5 and maximum value of 865,283.2 illustrate that (Wang & Feng, 2022). The mean of foreign direct investment (FDI) is -2.44e+08 (approximately -244 million USD) and the standard deviation is 1.21e+09 (1.21 billion USD). There is great variability in FDI inflows and outflows, the minimum value (-3.51e+09) and maximum value (1.24e+10) suggesting that some countries receive large investments such as Nigeria (US$5.3 billion), South Africa (US$4.4 billion), Angola (US$2.2 billion), Liberia (US$2 billion) and Ghana (US$0.61

billion) (World Bank, 2022), while others experience large disinvestment such as Central Africa Republic, Eritrea, Burundi and Comoros, which may be due to economic or political instability (Okara, 2023). The population figures range very widely, from a low of 81,131 people to a high of 22,1907,294.4 people. The mean population is 40.9 million and the standard deviation is 142 million. The large standard deviation indicates that the sample covers both least populated countries such as Seychelles, Comoros, Sao Tome and Principe and highly populated countries such as Nigeria (15.4%) · Ethiopia (8.7%) · Egypt (7.7%) · DR Congo (7.1%) · Tanzania (4.5%) · South Africa (4.3%) · Kenya (3.7%), as is typical in global datasets (Zhang & Tan, 2016). The mean of industrialization is 6.72e+09 (6.72 billion USD) with a large standard deviation of 2.49e+10 (24.9 billion USD). Levels of industrial activity show significant differences, wide range from 3,996,971 to 2.36e+11, which may be due to the developmental stage of various countries (Kuznets, 1973). The average value of renewable energy consumption with respect to the total energy consumption is 49.62% with the standard deviation of 34.33. This range of 0.005% to nearly 100% demonstrates a regional move towards sustainable energy in some regions such as Ethiopia, Kenya, Tanzania, Uganda, Rwanda and South Africa, while other regions depend on non-renewable sources such as Nigeria, Angola, Ghana among others (Nguyen & Kakinaka, 2019). Institutional quality finally averages at -0.714 (std. dev. = 0.70) with values between -2.22 and 1.04. These figures indicate large variation in governance and institutional effectiveness, where countries such as Mauritius, Botswana, South Africa, Cape Verde and Namibia are among the top scorers of institutional quality while Liberia, Congo Democratic and Somalia are the least performers (Karim *et al*., 2022).

Table 2: Descriptive statistics results

Variable	Obs	Mean	Std. Dev.	Min	Max
Carbon emission	552	47327.03	157595.7	53.5	865283.2
Foreign direct investment	552	-2.44e+08	1.21e+09	-3.51e+09	1.24e+10
Population	552	4.09e+07	1.42e+08	81131	221907294.4
Industrialization	552	6.72e+09	2.49e+10	3996971	2.36e+11
Renewable energy consumption	552	49.61874	34.32933	.0051146	99.97338
Institutional quality	552	-.7145176	.7029199	-2.224527	1.044383

Source: Authors computation

Correlation analysis

Correlation analysis aims at realizing the objective of knowing the nature and degree of relationship that exists between the variables under study. The pairwise correlation coefficients for the variables under investigation are shown in Table 3. A positive relationship is established between Carbon Emissions (CE) and Foreign Direct Investment (FDI) (0.3417), implying that countries with higher levels of FDI have higher levels of carbon emissions. There is a possibility that the concept of foreign investments in industries like manufacturing and energy cause a rise in economic activity, which in turn leads to an increase in carbon emissions (Науменко, 2021). Although FDI inflow is beneficial to economic growth, it may cause environmental degradation if FDI is concentrated in high-emission industries. There is a strong positive correlation between Carbon Emissions (CO2) and Population (POP) (0.6475), indicating that countries with larger populations also produce more carbon. That is in line with the idea that higher populations typically require more energy for transportation, industry, and residential use, resulting in higher emissions (Rahman & Alam, 2021). Population growth can also add pressure to resources and infrastructure, adding to environmental strain. The strongest correlation is between Carbon Emissions and Industrialization (IND) (0.6992). This means that as countries become more industrialized, their carbon emissions increase. Greenhouse gas emissions are mainly due to industrial activities, especially manufacturing, energy production, and transportation. This relationship is consistent with the large literature that demonstrates that industrialization increases carbon emissions, especially in developing countries where industrial processes tend to be carbon-intensive (Raheem & Ogebe, 2017).

Table 3: Correlation results

	CE	FDI	POP	IND	REC	IQ
Carbon emission	1.0000					
Foreign direct investment	0.3417*	1.0000				
Population	0.6475*	-0.1307*	1.0000			
Industrialization	0.6992*	-0.1383*	-0.9466*	1.0000		
Renewable energy consumption	-0.2582*	-0.0937*	-0.0955*	-0.1817*	1.0000	
Institutional quality	-0.1102*	-0.0921*	-0.1675*	-0.0848*	-0.4147*	1.000

Source: Authors computation

Notes: CE= Carbon Emissions; FDI= Foreign Direct Investment; POP=Population; IND= Industrialization; REC=Renewable Energy Consumption; 1IQ= Institutional Quality; ***σ**<0.05

On the contrary, Renewable Energy Consumption (REC) is negatively correlated with Carbon Emissions (-0.2582), indicating that greater use of renewable energy sources is linked to lower emissions. The reason for this is that renewable energy (e.g., solar, wind, hydro) has very low or negligible carbon emissions relative to fossil fuel-based energy sources (International Energy Agency, 2020). This negative relationship highlights the significance of renewable energy in helping a country cut its carbon footprint and achieve a low-carbon economy. Institutional Quality (IQ) has a small negative correlation with Carbon Emissions (-0.1102). Thus, better governance and stronger institutions lead to slightly lower carbon emissions among countries, as better governance and stronger institutions often correlate with stronger regulatory frameworks, environmental policies, and enforcement of sustainability standards (Karim *et al*., 2022). Strong institutions can help mitigate the negative environmental impacts of industrialization and population growth by fostering cleaner technologies and efficient resource management.

Regression results

The four models in the fixed effects regression table analyze the relationship between carbon emissions and various economic, energy, and institutional factors in Sub-Saharan Africa, with a specific focus on the moderating role of institutional quality in the link between renewable energy consumption and carbon emissions. Model 1 presents the baseline relationship using control variables only—foreign direct investment (FDI), population, and industrialization. FDI shows a strong and positive relationship with carbon emissions ($\beta = 0.478$, $p < 0.05$), suggesting that inflows are likely directed toward carbon-intensive sectors, such as extractive industries and manufacturing (Doytch, 2020). Population is negatively and significantly related to emissions ($\beta = -0.078$, $p < 0.05$), possibly due to efficiency gains in urban infrastructure and shared resource use (Shahbaz et al., 2017). Industrialization shows a strong positive impact on emissions ($\beta = 0.795$, $p < 0.01$), aligning with the dominance of fossil-fuel-based industrial growth in the region (Grossman & Krueger, 1995).

Model 2 introduced renewable energy consumption as an independent variable. The coefficient for renewable energy is negative and significant ($\beta = -0.073$, $p < 0.01$), confirming that increased use of renewable sources reduces carbon emissions. FDI and industrialization remain positively associated with emissions, while population switches to a positive and significant coefficient ($\beta = 0.075$, $p < 0.05$), possibly reflecting demographic pressures in energy-intensive urban centers when other variables are controlled for. Model 3 adds institutional quality as a moderator. Institutional quality shows a negative and statistically significant relationship with carbon emissions ($\beta = -0.105$, $p < 0.05$), suggesting that stronger governance can reduce environmental degradation, likely through policy enforcement and investment guidance (Yeboah et al., 2024). Renewable energy consumption remains negatively associated with emissions ($\beta = -0.120$, $p < 0.01$), reinforcing the idea

that renewables are effective in reducing environmental harm in regions with improved institutional capacity.

Model 4 includes the interaction term between renewable energy consumption and institutional quality. The interaction effect is negative and statistically significant ($\beta = -0.052$, $p < 0.05$), indicating that institutional quality strengthens the mitigating effect of renewable energy consumption on carbon emissions. In essence, renewable energy becomes more effective at reducing emissions when implemented in a context of strong institutions—through mechanisms such as regulatory enforcement, transparent energy governance, and incentive alignment. Notably, in this model, FDI, population, and industrialization coefficients become negative, which may suggest that strong institutional frameworks can reverse the environmental damage typically associated with these factors by guiding them toward greener practices. The incremental increase in R-squared values from Model 1 (0.6877) to Model 4 (0.7061) further demonstrates the importance of including institutional quality and its interaction with energy policy variables in explaining carbon emissions dynamics in Sub-Saharan Africa. This supports the hypothesis that good governance not only directly reduces emissions but also enhances the effectiveness of renewable energy adoption.

Table 4: Fixed regression results

Fixed effect model				
Carbon emissions	Model 1	Model 2	Model 3	Model 4
	Coef.	Coef.	Coef.	Coef.
Constant	.022 (0.020)	0.022 (0.021)	0.032 (0.021) **	0.052 (0.022) **
Foreign direct investment	0.478 (0.020) **	0.486 (0.021) **	0.468 (0.021) **	-0.105 (0.023) **
Population	-0.078 (0.022) **	0.075 (0.022) **	-0.105 (0.023) **	0.761 (0.021)**
Industrialization	0.795 (0.020) **	0.783 (0.021) **	0.769 (0.021) **	-0.136 (0.026) **
Renewable energy consumption		-0.073 (0.023) **	-0.120 (0.025)**	-0.094 (0.025) **
Institutional Quality			-0.105 (0.024)**	-0.106 (0.016) **
Renewable energy consumption * Institutional Quality				-0.052 (0.023)**
R-sq:	0.6877	0.6964	0.7036	0.7061
Number of Obs	839	839	839	839
Number of groups	24	24	24	24
F	657.35	472.15	389.53	328.54
Prob>F	0.0000	0.0000	0.0000	0.0000

Source: Authors computation

** $\rho < 0.05$, *P<0.1 standard errors in parentheses

CONCLUSION AND RECOMMENDATION

The fixed effects model results offer significant insights into the factors influencing carbon emissions in Sub-Saharan Africa, emphasizing the essential roles of renewable energy consumption and institutional quality. The positive relationship between FDI and carbon emissions in the first model indicates that investment flows predominantly target carbon-intensive sectors. The transition to a negative FDI-emissions relationship in the final model, when influenced by institutional quality, signifies the transformative capacity of robust institutions

in steering investment towards more sustainable options. Renewable energy usage exhibits a consistent and substantial inverse relationship with emissions, highlighting its efficacy in alleviating environmental degradation. The relationship between renewable energy and institutional quality further substantiates that governance frameworks substantially amplify the environmental advantages of renewable energy implementation. Moreover, institutional quality independently has a significant negative effect on emissions, underscoring its pivotal role in environmental governance. Given these findings, it is essential for policymakers, institutional leaders, and development stakeholders in Sub-Saharan Africa to incorporate governance changes into climate and energy initiatives. Fortifying institutional frameworks can augment regulatory enforcement, boost transparency, and stimulate investments in sustainable energy. Renewable energy policies must be supplemented by the enhancement of institutional capacity to guarantee their efficacy. Policymakers must prioritize institutional improvements that incorporate environmental responsibility and facilitate the execution of renewable energy regulations. Ultimately, utilizing institutions to enhance collaboration between the public and private sectors can magnify the effectiveness of renewable energy programs and advance enduring environmental sustainability throughout the region.

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