Economic Growth, Financial Development and Carbon Emissions. Does Institutional Quality Matter?

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A B S T R A C T

This study investigates the moderating role of institutional quality on the relationship between economic growth, financial development and carbon missions in Sub-Saharan Africa using a fixed effects panel regression model. The analysis reveals that economic growth and financial development have a positively and significantly relationship with carbon emissions, suggesting that these factors contribute to environmental degradation when sustainability measures are lacking. Conversely, institutional quality exhibit negative and significant effects on emissions, highlighting its potential in mitigating environmental harm. Importantly, interaction terms show that institutional quality moderates the positive effects of economic growth and financial development on carbon emissions, implying that strong institutions can reduce the environmental costs of development. These findings underscore the critical role of institutional quality in shaping the environmental outcomes of economic and financial progress. Policy recommendations include strengthening institutional frameworks, promoting green finance, and aligning economic growth with sustainable development goals to achieve low-carbon growth in the region.

INTRODUCTION

Climate change resulting from global warming is a significant topic of discourse among scientists and policymakers at both international and local levels (Eitan, 2021). The indicators of climate change are more apparent. Climate change may occur naturally or as a result of human activity, and as the latter is inescapable, definitions of climate change have predominantly focused on anthropogenic causes (Trenberth, 2018). Carbon dioxide (CO_2) emissions constitute the primary driver of climate change. CO_2 significantly influences both production and consumption, such as

fossil fuel utilization, which propels economic advancement (Anwar et al., 2019). According to Alagidede, Adu, and Frimpong (2016), "the environment is man, and man is the environment," since humans use natural resources from the environment as inputs for producing goods and services, while also utilizing the environment as a repository for waste. The environment is essential for safeguarding all living organisms, from fundamental life necessities to intricate nourishment requirements.

When an atmosphere excessively absorbs carbon dioxide, carbon monoxide, nitrous oxide, and other gaseous components, it generates greenhouse gases. Seventy percent of all greenhouse gas emissions consist of carbon dioxide (Espoir, Sunge & Bannor, 2021). Researchers worldwide have been investigating greenhouse gas emissions due to the rising trends in air pollution data and environmental degradation events. SSA nations are susceptible to climate change (EPA, 2021; Serdeczny et al., 2017). Recently, greenhouse gas emissions have escalated globally, particularly in Sub-Saharan Africa, as indicated by empirical studies on environmental pollution. According to Andres et al. (2011), the Carbon Dioxide Information Analysis Centre reported that fossil fuel consumption contributes 11.5% of yearly carbon dioxide emissions. African nations like Libya, South Africa, the Seychelles, and Equatorial Guinea had carbon dioxide emissions exceeding the global average of 1.3 metric tons of carbon annually (Andres et al., 2011).

The relationship between economic growth, energy consumption, and carbon emissions is becoming a significant subject of inquiry among scholars (Raihan & Tuspekova, 2022). Factors such as population growth, energy consumption, economic expansion, and heightened demand for goods and services have exacerbated carbon dioxide emissions in Sub-Saharan Africa (Alaganthiran & Anaba, 2022). It is emphasized that energy utilization for economic development has resulted in significant carbon emissions, contributing to climate change and an uptick in respiratory diseases and asthma. For decades, sub-Saharan Africa (SSA) has been characterized by low economic performance, grappling with significant developmental issues like food insecurity and poverty.

The relationship between financial development and carbon dioxide (CO_2) emissions has emerged as a significant topic in contemporary academic discussions. Two contrasting perspectives prevail in this discourse. The initial proposition indicates that financial development can markedly diminish CO_2 emissions. Advocates contend that improved financial institutions draw foreign direct investment (FDI) and facilitate research and development (R&D), promoting economic growth while mitigating environmental damage (Acheampong, 2019; Tamazian et al., 2009). Foreign Direct Investment facilitates the transfer of green technologies to host nations, allowing companies to implement cleaner and more energy-efficient production techniques (Paramati et al., 2017). Moreover, accessible and affordable financing can stimulate both public and private investments in sustainable technology, thus reducing carbon emissions (Dasgupta et al., 2001; Yuxiang & Chen, 2010). Financial markets can enhance resource allocation and promote corporate governance procedures that prioritize environmental performance (Claessens & Feijen, 2007; Frankel & Rose, 2002; Klassen & McLaughlin, 1996).

In contrast, the second position argues that financial development may exacerbate CO_2 emissions. This perspective posits that readily available credit may result in heightened consumption of energy-intensive products and expanded industrial activity, both of which contribute to elevated emissions (Acheampong, 2019; Sadorsky, 2010). Companies, supported by financial advancement, may augment production capabilities and invest in emissions-intensive technology. Furthermore, banks frequently exercise caution in financing such green innovations due to the intangible and specialized characteristics of these investments, rendering them challenging to collateralize (Carpenter & Petersen, 2002; Hall & Lerner, 2010; Minetti, 2011). Thus, this financial conservatism may impede advancements in cleaner production and environmental sustainability (Aye & Edoja, 2017).

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 underexplored (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, government 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, understanding their influence on carbon emissions is crucial. This study investigates the influence of institutional quality on carbon emissions in a panel of 30 Sub-Saharan African countries from 2000 to 2021, addressing the existing information gap. The study seeks to address two critical inquiries to fulfill its objective: (i) Does economic growth influence carbon emissions in sub-Saharan Africa? Does financial development influence carbon emissions in sub-Saharan Africa? (iii) Does the quality of institutions moderate the relationship between economic growth, financial development, and carbon emissions in sub-Saharan Africa?

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Economic growth and carbon emissions

Ghazouani and Maktouf (2024) examined the impact of natural resource exploitation, trade liberalization, and economic growth on carbon emissions in oil-exporting nations from 1971 to 2014. The study examined this association utilizing the panel autoregressive distributed lag model and several econometric methods that account for cross-sectional dependence. The research indicated that the exhaustion of natural resources and heightened trade had a persistent negative impact on environmental quality. Our research has demonstrated the validity of the Kuznets Environmental Curve for oil-exporting countries. An examination of causation revealed a bidirectional relationship among natural resources, economic growth, and CO2 emissions, alongside a unidirectional relationship between trade openness and CO2 emissions.

Li and Wei (2021) examined the impact of carbon emissions on economic growth across 30 Chinese provinces from 1987 to 2017, employing balanced panel data and the panel smooth transition regression model. Estimation was conducted utilizing the complete sample alongside distinct subsamples for the northern and southern regions. Empirical evidence revealed non-linear relationships among carbon emissions, financial development, openness, innovation, and economic growth. Moreover, carbon emissions undermine the beneficial effects of financial development and innovation on economic growth, a correlation substantiated by the role of energy consumption as an intermediary element. The investigated subsample indicated notable regional variations in the impact of carbon emissions on economic growth, with the northern region demonstrating a lower carbon emissions threshold yet a more rapid transition rate.

Islam et al. (2021) contended that the recent remarkable economic expansion of Bangladesh is attributable to multiple causes, including globalization, foreign direct investment (FDI), commerce, urbanization, energy consumption, innovation, and institutional quality. These factors

have also influenced the nation's natural environment. Previous studies seldom combined these processes, particularly innovation and institutional quality, to examine their impact on environmental deterioration in Bangladesh. This study sought to examine the influence of globalization, foreign direct investment, economic growth, trade, innovation, urbanization, and energy consumption on CO_2 emissions in Bangladesh from 1972 to 2016. The research employed a dynamic ARDL simulations model created by Jordan and Philips (2018) to analyze the correlation between these variables and CO_2 emissions, considering the impact of institutional quality. The investigation's findings indicated that globalization, foreign direct investment, and innovation negatively affected CO_2 emissions, resulting in a deterioration of environmental quality. Conversely, economic expansion, commerce, energy consumption, and urbanization positively influenced CO_2 emissions, therefore exacerbating environmental degradation in both the short and long term. The quality of institutions, as assessed by the political terror scale (PTS), positively influenced CO_2 emissions, resulting in a decline in environmental quality in both the short and long run.

Acheampong, Dzator, and Savage (2021) investigated the temporal cause-and-effect link among institutions, renewable energy, carbon emissions, and economic growth in 45 sub-Saharan African nations. The research utilized annual data spanning from 1960 to 2017. We utilized the generalized method of moments panel vector autoregression (GMM-PVAR) methodology to examine the relationships. The findings suggested that a direct cause-and-effect relationship between institutions and economic growth does not exist. There exists a bidirectional causal relationship between economic growth and renewable energy. Our findings indicated a strong correlation between economic growth and carbon emissions. Furthermore, institutions are increasingly predisposed to mitigate carbon emissions and advocate for renewable energy. Our analysis, however, revealed no evidence of a direct association between carbon emissions and renewable energy.

Rahaman, Rahaman, Hossain, and Chen (2022) conducted a study to investigate the impact of foreign direct investment (FDI), tourism, power consumption, and economic development on CO_2 emissions in Bangladesh from 1990 to 2019. The empirical findings demonstrated that factors such as foreign direct investment (FDI), energy consumption, and economic development significantly and positively influence carbon dioxide (CO_2) emissions over the long term. Conversely, tourism exerts a deleterious effect over time. The squared GDP variable demonstrates a substantial negative coefficient. This indicates that in Bangladesh, there exists an inverted U-shaped correlation between CO_2 emissions and economic progress. As a result, the EKC hypothesis has been substantiated. In the short run, CO_2 emissions were not substantially influenced by energy consumption, economic growth, GDP, or tourism. The sole variables that demonstrate negative and statistically significant coefficients are to FDI. The expected ECM coefficients are both detrimental and statistically significant. The entire system adapts at a rate of 60% according to this data. The Granger causality study revealed a unidirectional causative association among energy consumption and CO_2 emissions, CO_2 emissions and economic development, electricity consumption and economic development, foreign direct investment, and CO_2 emissions.

Onofrei, Vatamanu, and Cigu (2022) conducted a study to investigate the relationship between economic growth and CO_2 emissions in the 27 EU member states from 2000 to 2017 via a panel methodology. We utilized a qualitative sequential methodology that incorporated empirical analysis to guarantee consistency and validity in our research. Furthermore, we employed quantitative methodologies including Dynamic Ordinary Least Squares (DOLS), unit root tests, and cointegration approaches. The results demonstrated a sustained cointegrating association between economic growth and CO_2 emissions in EU nations. The DOLS approach revealed a statistically significant effect of economic growth on CO_2 emissions for both estimator versions. It specifically indicated that, on average, a 1% variation in GDP corresponds to a 0.072 variation in CO_2 emissions.

Fávero et al. (2022) investigated the global relationship between economic growth and CO2 emissions. Following an extensive review of many analogous research, we devised a novel quantitative analytical framework that accurately encapsulates the contextual viewpoints of 187 nations from 1800 to 2016. The multilevel model presented in this study accurately captured the links between fixed and random effects factors related to GDP and carbon dioxide emissions. Moreover, it provided new evidence concerning the occurrence trends of the phenomenon under investigation across many countries and temporal contexts, while considering the discrepancies in these data. The model confirmed a positive and statistically significant correlation between economic development and carbon emissions per country, while also underscoring the positive impacts of linear and cubic income on CO2 emissions, alongside the negative influence of quadratic income. This reinforces the validity of the traditional N-shaped curve for the examined period. H1*. Economic growth has a significant effect on Carbon emissions in SSA*

Financial development and carbon emissions

According to Zhao and Yang (2020), it is crucial to reduce CO2 emissions in China, as it is the largest contributor to CO2 emissions. The primary objective of this study was to examine the correlation between financial development and CO2 emissions at the local level in China through static and dynamic analysis, a topic that has received limited attention. Principal Component Analysis (PCA) is utilized to mitigate the issue of indicator correlation that commonly arises in previous studies. Its purpose is to create a provincial financial development index for China starting from the year 2001. By conducting a static panel analysis, it was determined that a single unit increase in the provincial financial development level leads to an average reduction of 4%–5% in CO2 emissions. However, this relationship does not hold true for the provinces of Zhejiang, Fujian, Sichuan, Yunnan, Shaanxi, and Xinjiang, as their CO2 emissions actually increase. Over the long term, there is evidence of an inverse association between regional financial development and CO2 emissions, although this is not the case in the short term. The dynamic analysis results indicated that the progress of regional financial development has had a substantial negative impact on CO2 emissions.

Habiba and Xinbang (2022) conducted a study to examine the influence of financial market development, institution development, and their sub-indices on CO2 emissions. The study recognized the complex and multifaceted nature of financial development. In order to enhance our understanding of the relationship between financial development and CO2 emissions, we utilize four financial market indices (overall financial market development, FM-access, FM-depth, and FM-efficiency) and four financial institution indices (overall financial institution development, FI-access, FI-depth, and FI-efficiency). The study employed a two-stage system Generalized Method of Moments (GMM) approach and utilized panel data from both developed and emerging countries spanning the years 2000 to 2018. The empirical findings demonstrated that the general development of the financial market, as well as its specific components (FM-access, FM-depth, and FM-efficiency), led to a decrease in CO2 emissions in both developed and emerging nations.

Raheem, *et al.,* (2020) examined the impact of information and communication technology (ICT) and financial development (FD) on carbon emissions and economic growth in the G7 countries from 1990 to 2014. Through the utilization of PMG, we have discovered that Information and Communication Technology (ICT) has a significant and lasting positive impact on emissions. On the other hand, Foreign Direct Investment (FD) has been found to have a limited influence on emissions. The interaction term between Information and Communication Technology (ICT) and Financial Development (FD) yields negative coefficients. Furthermore, it has been observed that both variables have a detrimental effect on economic growth.

According to Shoaib, *et al.,* (2020), financial development played a crucial role in promoting both rapid economic growth and the emission of CO2 into the environment. The objective of this study was to examine the causal relationship between financial development and CO2 emissions in

G8 and D8 countries from 1999 to 2013. We employed Principal Component Analysis (PCA) to construct a financial development index based on its five constituent sub-components. Second-generation panel unit root tests are utilized to assess the stationary level and address the existence of cross-sectional dependence in panel data. The empirical findings from the PMG-panel ARDL technique indicated that there is a significant and positive relationship between financial development and carbon emissions at a 1% statistical significance level in both panels over the long-term. The influence of financial development is more pronounced in D8 countries, while energy consumption has a stronger effect in G8 countries. Energy consumption and trade liberalization have a positive impact, while GDP has a significant negative effect on carbon emissions at a 1% statistical significance level. The D-H causality test results indicated that most variables exhibit one-way causality towards CO_2 emission in both panels, with the exception of financial development and energy use, which demonstrate two-way causality in the G8 panel exclusively. In their study, Rafique, *et al.,* (2020) found that previous research on the relationship between foreign direct investment and economic growth failed to consider the significant influence of technological innovation and financial development on environmental costs. The significant economic growth and subsequent rapid urbanization in BRICS countries have resulted in a substantial increase in energy demands, which has led to environmental degradation. The study aimed to investigate the impact of foreign direct investment, technological innovation, and financial development on carbon emissions in BRICS member countries using data from 1990 to 2017. The results confirmed a significant cross-sectional interdependence among the countries in the panel. The Augmented Mean Group (AMG) estimator revealed a negative and statistically significant long-term relationship between foreign direct investment, technological innovation, and financial development in the BRICS countries and CO_2 emissions. On the other hand, economic growth, trade openness, urbanization, and consumption of energy were found to have a statistically significant and positive impact on carbon emissions. The present study opted to utilize the Dumitrescu and Hurlin panel causality test to investigate the direction of causality. The findings indicated that there is a two-way causal relationship over a long period of time between financial development, economic growth, trade openness, urbanization, energy use, and CO_2 emissions. However, there is only a one-way causal relationship between foreign direct investment and carbon emissions.

Xu, *et al.,* (2018) conducted a study to investigate the impact of financial development on environmental degradation in Saudi Arabia from 1971 to 2016. The study controlled for the effects of globalization and electricity consumption in the model. The autoregressive distributive lag (ARDL) method is used to analyze long-run relationships, while the vector error correction method (VECM) is used to examine causal relationships. The empirical findings demonstrated that the advancement of financial systems had a direct impact on the increase of CO_2 emissions and the deterioration of environmental conditions. The findings further indicated that the impact of globalization on environmental degradation is negligible, while electricity consumption emerges as the primary factor driving the increase in CO_2 emissions in Saudi Arabia. Furthermore, there was an inverse connection between globalization and CO_2 emissions over an extended period of time, and there is a mutual causal relationship between financial development and CO_2 emissions.

Khan, *et al.,* (2018) investigated the impact of financial development, inequality of income, consumption of energy, and per capita GDP on carbon dioxide (CO_2) emissions, as well as the presence of the environmental Kuznets curve (EKC), in three developing Asian countries: Bangladesh, India, and Pakistan. The empirical investigation utilized panel data from 1980 to 2014 and employed the Fully Modified Ordinary Least Squares (FMOLS) method to analyze the Stochastic Impacts by Regression on Population, Affluence, and Technology model. The findings indicated a notable inverse correlation between financial development and CO_2 emissions in the three chosen Asian nations, except for India. The findings additionally demonstrated that income inequality in Pakistan and India led to a decrease in CO_2 emissions, whereas the outcome for Bangladesh was the opposite. In addition, energy consumption had a notable and favorable impact on carbon

dioxide (CO2) emissions in Bangladesh, Pakistan, and India. The results of our empirical analysis, which involved evaluating the long-run and short-run elasticity, indicate that the Environmental Kuznets Curve (EKC) holds true in both Pakistan and India.

H2. *Financial development has a significant effect on Carbon emissions in SSA*

Institutional quality and carbon emissions

In their study, Bakhsh, Yin & Shabir, (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. 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 was 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.

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) investigated 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.

Yuan, et al., (2022) 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.

H3. *Institutional quality has a moderating significant effect on the relationship between:*

 a) *Economic growth and Carbon emissions in SSA*
 b) *Financial development 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 600 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
Economic Growth	Independent Variable	Measured using GDP	EG
Financial Development	Independent variable	Ratio of financial institutions' <u>assets</u> to GDP (Adu, Marbuah & Mensah, 2013)	FD
Institutional Quality	Moderator variable	Composite index of political stability, control of corruption, regulatory quality, the rule of law, voice and accountability, and government effectiveness (Kaufmann *et al.*, 2009; Langbein and Knack, 2010)	IQ
Foreign Direct Investment	Control variable	FDI is the measure of investment inflows (Pattayat, 2016)	FDI

Variable	Category	Operationalization	Acronym
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: Authors computation

Regression models

The following regression equations were adopted to test the proposed hypotheses:
Model 1: testing the effect of control variables on carbon emissions.

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

Model 2: testing the effect of economic growth and financial development on carbon emissions.

$$CE_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 FD_{it} + \beta_3 FDI_{it} + \beta_4 POP_{it} + \beta_5 IND_{it} + \varepsilon_{it} \dots\dots\dots\dots(2)$$

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

$$CE_{it} = \beta_0 + \beta_1 EG_{it} + \beta_2 FD_{it} + \beta_3 IQ_{it} + \beta_{(4-6)} Controls + \varepsilon_{it} \dots\dots\dots\dots\dots(3)$$

Model 4: Testing the interaction between economic growth and institutional quality.

$$CE_{it} = \beta_0 + \beta_1 EG_{it} + \beta_2 FD_{it} + \beta_3 IQ_{it} + \beta_4 RE * IQ_{it} + \beta_{(5-7)} Controls + \varepsilon_{it} \dots\dots\dots (4)$$

Model 5: Testing the interaction between financial development and institutional quality.

$$CE_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 FD_{it} + \beta_3 IQ_{it} + \beta_4 RE * IQ_{it} + \beta_5 FDI * IQ_{it} + \beta_{(6-8)} Controls + \varepsilon_{it} .(5)$$

Empirical findings and discussion

Diagnostic tests

Hausman test (p<0.05) 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 (vif=1.22) results indicated that the model did not suffer from multicollinearity, Breusch-Pagan test (p>0.05) indicated that the model did not suffer from heteroscedasticity and Breusch-Godfrey test results (p>0.05) 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 (Alaganthiran & Anaba, 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). Economic growth shows a high mean (6.09e+10) but also considerable variability, reflecting diverse economic trajectories within Sub-Saharan Africa with countries such as Niger, Senegal, Libya, Rwanda, Cote d'Ivoire, Ethiopia, Benin, Djibouti, Tanzania, Togo and Uganda registering higher economic growth while countries such as Equatorial Guinea, Sudan, São Tomé and Príncipe registering lower economic growth. The average index score of financial development is 1.265, with large standard deviation of 3.51, minimum of -9.88 and maximum of 18.39. This implies large differences in financial sector development, with some countries such as South Sudan and Somalia having underdeveloped financial systems and others such as Kenya, Mali, Senegal, and South Africa with highly developed financial markets (Zhang, 2011). 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, Qamruzzaman & Jahan, 2023).

Table 2: Descriptive statistics results

Variable	Obs	Mean	Std. Dev.	Min	Max
Carbon emission	600	47327.03	157595.7	53.5	865283.2
Foreign direct investment	600	-2.44e+08	1.21e+09	-3.51e+09	1.24e+10
Population	600	4.09e+07	1.42e+08	81131	221907294.4
Industrialization	600	6.72e+09	2.49e+10	3996971	2.36e+11
Economic Growth	600	6.08e+10	2.26e+11	5.77e+07	2.06e+12
Financial development	600	1.265022	3.510553	-9.883455	18.39591
Institutional quality	600	-.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 (Wang *et al.*, 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 (CO_2) 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

(Alam *et al*., 2016). 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	FD	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			
Economic growth	-0.2582*	-0.0937*	-0.0955*	-0.1817*	1.0000		
Financial development	0.1625*	0.1269*	0.0890*	0.0227	0.0395	1.0000	
Institutional quality	-0.1102*	-0.0921*	-0.1675*	-0.0848*	-0.4147*	-0.1187*	1.000

Source: Authors computation

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

A strong positive correlation exists between carbon emissions and economic growth (r = 0.6955*). This suggests that higher economic activity leads to increased emissions. The Environmental Kuznets Curve (EKC) hypothesis suggests that emissions initially rise with economic growth but eventually decline as countries adopt cleaner technologies and environmental policies (Grossman & Krueger, 1995). The correlation between Carbon Emissions and Financial Development (FD) (0.1625) is weak and positive. This implies that carbon emissions may be slightly higher in more financially developed countries (Zhang, 2011) as this may be due to greater economic activities and industrialization (Zhang, 2011) which lead to energy consumption. Nevertheless, the strength of this relationship is not as strong as other factors, implying that the effect of financial development on emissions may be mediated by other factors, for example, energy policies or industrial structures. 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, Qamruzzaman & Jahan, 2023). 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 five models in the table below analyzed the relationship between carbon emissions, economic growth, financial development, and institutional quality in Sub-Saharan Africa using a fixed effects model. Model 1 incorporates only the control variables—foreign direct investment (FDI), population, and industrialization. The results indicate that FDI has a positive and statistically significant relationship with carbon emissions ($\beta = 0.478$, $p < 0.05$), implying that higher FDI inflows are associated with increased emissions. This is likely because FDI in the region often targets extractive and manufacturing industries, which are energy-intensive and environmentally detrimental (Thao & Huy, 2024). This supports the "pollution haven hypothesis," where developing countries attract environmentally harmful investments due to lax environmental regulations (Cole, 2004).

Population displays a negative and significant coefficient ($\beta = -0.078$, $p < 0.05$), suggesting that increased population densities may contribute to lower per capita emissions. This could be due to more efficient resource use, shared infrastructure, and urbanization benefits such as public transportation systems and better waste management (Martínez-Zarzoso & Maruotti, 2011). Industrialization shows a strong positive association with carbon emissions ($\beta = 0.795$, $p < 0.05$), consistent with the literature which highlights the fossil fuel dependence of industrial growth in Sub-Saharan Africa (Grossman & Krueger, 1995).

Model 2 introduces the independent variables—economic growth and financial development—alongside the control variables. Economic growth is positively and significantly associated with carbon emissions ($\beta = 0.704$, $p < 0.05$), aligning with the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental degradation initially rises with economic growth (Grossman & Krueger, 1995). In the context of Sub-Saharan Africa, growth is often accompanied by increased energy consumption and infrastructure expansion, which contribute to carbon emissions (Shahbaz et al., 2017). Financial development also exhibits a positive and significant effect on carbon emissions ($\beta = 0.039$, $p < 0.05$), suggesting that financial sector growth may facilitate investments in carbon-intensive industries unless directed by sustainable finance policies (Tamazian et al., 2009).

Model 3 adds the moderator variable, institutional quality, into the regression. Institutional quality is negatively and significantly related to carbon emissions ($\beta = -0.016$, $p < 0.05$), indicating that improved institutional frameworks can help reduce environmental degradation. Institutions play a critical role in shaping environmental outcomes through policy enforcement, promotion of environmental regulations, and alignment of economic activities with sustainable development goals (Rodrik, Subramanian, & Trebbi, 2004).

Model 4 introduces the interaction between economic growth and institutional quality. The interaction term is negative and significant ($\beta = -0.444$, $p < 0.05$), indicating that institutional quality moderates the relationship between economic growth and carbon emissions. This implies that while economic growth increases emissions, strong institutions can mitigate this effect by facilitating green investments and enforcing environmental safeguards (Baumol & Oates, 1988). Institutional quality, therefore, plays a mediating role in decoupling economic expansion from ecological degradation.

Model 5 explores the moderating role of institutional quality on the relationship between financial development and carbon emissions. The interaction term is also negative and statistically significant ($\beta = -0.036$, $p < 0.05$), implying that institutional quality can steer financial development towards more sustainable outcomes. This supports findings by Tamazian and Rao (2010), who argue that good governance and regulatory institutions are necessary to ensure that financial development contributes to environmental sustainability.

Overall, the inclusion of interaction terms in Models 4 and 5 increases the explanatory power of the models (R^2 rises from 0.9445 in Model 3 to 0.9498 in Model 5), highlighting the crucial role of institutional quality in shaping the environmental consequences of economic and financial progress. These findings underscore that institutional frameworks are essential in ensuring that economic growth and financial development do not come at the expense of environmental sustainability in Sub-Saharan Africa.

Table 4: Fixed model results

Fixed effect model					
Carbon emissions	Model 1	Model 2	Model 3	Model 4	Model 5
	Coef.	Coef.	Coef.	Coef.	Coef.
Constant	.022 (0.020)	0.031 (0.010) **	0.036 (0.011) **	0.103 (0.014) **	0.099 (0.014)**
Foreign direct investment	0.478 (0.020) **	-0.038 (0.012) **	-0.037 (0.012) **	-0.040 (0.011) **	-0.042(0.011)**
Population	-0.078 (0.022) **	-0.154 (0.024) **	-0.167 (0.025) **	-0.187 (0.024)**	-0.184 (0.024)**
Industrialization	0.795 (0.020) **	0.904 (0.034) **	0.925 (0.036) **	1.697 (0.114) **	1.696 (0.112)**
Economic Growth		0.704 (0.011) **	0.701 (0.0120**	0.316 (0.055) **	0.314 (0.054)**
Financial Development		0.039 (0.010)	0.038 (0.010)**	0.035 (0.009)**	0.039 (0.009)**
Institutional Quality			-0.016 (0.10)**	-0.106 (0.016) **	-0.103 (0.016)**
Economic growth*Institutional Quality				-0.444 (0.063)**	-0.446 (0.062)**
Financial development*Institutional Quality					-0.036 (0.008)**
R-sq:	0.6877	0.9441	0.9445	0.9481	0.9498
Number of Obs	600	600	600	600	600
Number of groups	24	24	24	24	24
F	657.35	2193.35	1833.27	1714.89	1554.84
Prob>F	0.0000	0.0000	0.0000	0.0000	0.0000

Source: Authors computation

CONCLUSION AND RECOMMENDATIONS

The empirical results from the fixed effects models underscore the intricate relationship between carbon emissions and significant economic, financial, and institutional variables in Sub-Saharan Africa. The relationship between carbon emissions and foreign direct investment (FDI), economic growth, financial development, and industrialization indicates that present development paths are environmentally unsustainable. The detrimental impact of institutional quality, both directly and in moderating the effects of economic growth and financial development, underscores the essential role of robust governance in alleviating environmental degradation. The moderation effects demonstrate that robust institutions can successfully separate economic growth from environmental degradation by directing investments and growth towards more sustainable trajectories.

Policymakers should prioritize the enhancement of institutional frameworks to align economic and financial development with environmental objectives based on these findings. This involves strengthening regulatory enforcement, fostering transparency, and encouraging green investments via supportive legal and financial frameworks. Simultaneously, the attraction of foreign direct investment must incorporate environmental safeguards to direct capital towards low-emission sectors. Financial sector reforms must integrate green finance policies to direct credit towards

sustainable enterprises. Furthermore, the integration of sustainability into industrial and economic policies, the promotion of renewable energy adoption, and the encouragement of innovations in clean technologies via public-private partnerships are essential for attaining low-carbon, inclusive growth throughout the region. Embedding sustainability in institutions and development strategies enables Sub-Saharan Africa to achieve economic transformation while safeguarding its environmental future.

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