Teklie, Derese Kebede; Yağmur, Mete Han

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International Journal of Energy Economics and Policy

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(1), 121-140.

Effect of Economic Growth on CO_2 Emission in Africa: Do Financial Development and Globalization Matter?

Derese Kebede Teklie[1]*, Mete Han Yağmur[2]

[1]Graduate School, Istanbul Technical University, Istanbul, Turkiye, [2]Department of Economics, Istanbul Technical University, Istanbul, Turkiye. *Email: teklie18@itu.edu.tr

Received: 08 September 2023 **Accepted:** 10 December 2023 **DOI:** https://doi.org/10.32479/ijeep.15141

ABSTRACT

Carbon emissions are a global issue that has drawn policymakers' and scholars' attention. This study delved into examining the effect of globalization and financial development on carbon emissions within 52 African economies from 1997 to 2021. Energy consumption and population size were also considered controlling factors influencing carbon emissions. The study employs a two-step system-generalized method of moment (GMM) to analyze the effects, using the KOF Globalization Index and the IMF's Financial Development Index. The results indicate that carbon emissions increase with economic growth, energy consumption, and population size. Moreover, this study supports the Environmental Kuznets Curve (EKC) hypothesis. The study also reveals that globalization and its sub-indices, financial development, and financial institutions exhibit a linearly increasing role in carbon emissions. However, financial markets have a negligible effect. Nonlinearly, the squared of globalization and its sub-indices of economic and social dimensions, squared financial development, and its sub-indices exhibit a negative impact, portraying an inverted U-shaped association with carbon emissions. Meanwhile, political globalization follows a U-shaped trend. Additionally, globalization, financial development, and their sub-indices moderate carbon emissions. The implications of these findings underscore the importance of sustainable practices, green financing, and collaborative partnerships for a more environmentally sustainable path.

Keywords: Africa, CO_2 Emission, Economic Growth, Financial Development, Globalization, GMM
JEL Classifications: F64, O44, O55, Q43, Q56

1. INTRODUCTION

In recent decades, the world has been confronted with two intertwined problems: achieving economic growth and addressing the urgent issue of climate change. Economic growth has been a critical engine of progress, pulling millions out of poverty and developing societies (Zhu et al., 2022). Nonetheless, this advancement often exacts a significant toll on the environment, contributing to rising carbon emissions and aggravating the climate change problem (Nahrin et al., 2023). Carbon emissions represent the predominant greenhouse gas responsible for global warming, accounting for over 60% of global greenhouse gas emissions (EPA, 2018).

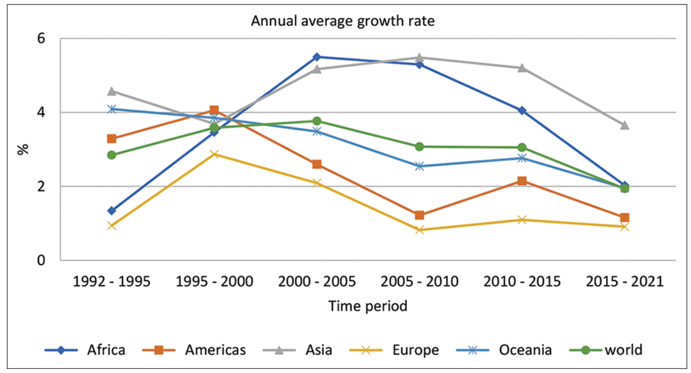
Meanwhile, increased atmospheric carbon levels negatively impact economic growth, the environment, and human health. These detrimental impacts encompass climate-related expenses, increased healthcare costs stemming from air pollution, and disruptions to critical infrastructure (Boamah et al., 2017; Dechezleprêtre et al., 2020). Also, carbon emissions keep the Earth from cooling, which elevates temperatures in different geographies and causes irreversible climatic changes such as flooding, water scarcity, erosion, and acid rain. Excessive carbon emissions further threaten human health through polluting the air, spreading diseases, and causing food shortages (IPCC, 2019). Therefore, it has become increasingly crucial to grasp the origins of carbon emissions and their connection to economic growth (Mitić et al., 2023). Thus, this study highlights the significant role played by financial development (FD) and globalization in the intricate relationship between economic growth and carbon emissions.

The role of FD and globalizations in the growth- emissions nexus is complex and multifaceted. Financial development serves as a vital funding source for various projects and is deeply intertwined with both economic growth and environmental well-being. An effectively functioning financial sector facilitates efficient capital allocation, mobilizes savings, and encourages productive venture investments in energy-efficient technologies that aim to minimize carbon emissions (Acheampong, 2019). Moreover, as economies progress and financial systems mature, there is an expansion in credit availability and investment opportunities (Abbas et al., 2022). This expanded access empowers entrepreneurs and businesses to engage in environmentally friendly innovation, ultimately contributing to enhanced environmental conditions (Abid et al., 2022). FD can also improve environmental quality by increasing productivity and abetting societies' access to new technologies (Aluko and Obalade, 2020). Globalization can also help to reduce carbon emissions by sharing knowledge, expertise, and best practices about sustainable practices and energy-efficient technologies (Zaidi et al., 2019).

Financial development and globalization may also have adverse impacts on environmental quality. FD can increase emissions by expanding fossil fuel-dependent industries to meet rising energy demands (Shahbaz and Lean, 2012). As countries pursue financial development, they frequently rely on nonrenewable energy to drive economic growth, even though these energy sources emit significant amounts of greenhouse gases (Awodumi and Adewuyi, 2020). This produces more carbon dioxide and contributes to climate change and environmental degradation. Also, as people's incomes increase, economic development leads to more consumption and production (Wang et al., 2020), leading to increased carbon emissions. In addition, investments in environmental degradation driven by financial institutions prioritize maximizing profits over environmental impacts (Habiba et al., 2021), further increasing carbon emissions and causing climate change. Also, globalization has the potential to facilitate a phenomenon called "race to the bottom," wherein nations endeavor to attract investments by implementing lax environmental regulations (Acheampong, 2022). This could potentially result in a significant increase in carbon emissions. Moreover, globalization can cause more carbon emissions through increasing energy consumption (Antweiler et al., 2001) and natural resource depletion (Panayotou, 2000). Consequently, the Earth's climate has undergone disturbances, resulting in increased extreme weather phenomena, elevated sea levels, and ecological imbalances.

Financial development and globalization are probably affecting the African economies more than any other part of the world at the present economic setup. Although many nations in Africa are classified as low-income, the continent has witnessed remarkable economic growth in recent years, establishing itself as the world's fastest-growing region. The continent's annual average growth rate is 3.6%, above the global average of 3% for 1992-2021 (UNCTAD, 2021) (Figure 1). Along with economic growth, the continent is experiencing fast industrialization and urbanization. For instance, according to the OECD (2020) report, an additional 950 million city dwellers will exist in Africa by 2050.

Figure 1: Economic growth of selected economic regions (1992-2021)



Source: UNCTAD database, 2021

To support and catalyze this growth, African countries have, since the 1990s, made concerted efforts to deepen, streamline, and strengthen their financial systems. However, despite these endeavors, Africa's financial system is weak and not as developed, and impedes the transfer of environmentally sustainable green technologies (Acheampong, 2019). Moreover, while many financial institutions in Africa contribute to economic growth, they are also likely to finance polluting projects that rely on outdated technologies, contributing to carbon emissions.

Also, globalization has brought economic benefits to Africa, with increased global income leading to greater demand for African goods and natural resources (Iyoboyi et al., 2020). However, this growing demand for resources has resulted in higher energy consumption (Aladejare, 2022), which lowers environmental quality in Africa. Furthermore, globalization is the main factor that causes deforestation, natural resource depletion and global warming (Shahbaz et al., 2017).

Recent data and research also underscore the adverse environmental consequences of Africa's economic growth. While Africa contributes the least to global ecological pollution (only 3.8% compared to the United States' 17%, China's 23.3%, and the EU's 13.0%), carbon emissions have risen in the continent (CDP, 2020). According to Statista (2021), carbon emissions in Africa increased by 4.6% per year between 1995 and 2020, rising from 7.2 billion tons in 1995 to 11.95 billion tons in 2020, a total increase of 67.5%. Between 1990 and 2017, Africa's energy-related Carbon emissions grew by 123%, which was much faster than the global average of 60%, and about 55% of the countries that have been affected by extreme environmental problems associated with Carbon emissions are from the continent (Ayompe et al., 2020; Maplecroft, 2011). Furthermore, recent forecasts suggest that carbon emissions in Africa are projected to increase by 30% by 2050, reaching a total of 1,550 million tons (Steckel et al., 2020). This projected increase in African emissions contradicts the critical target of achieving a 32% reduction by 2030, which is essential for fulfilling UN Sustainable Development goals and the Paris Agreement for 2050. Thus, estimating the role of globalization and FD on emissions is of utmost importance for Africa as it formulates development strategies and policies to mitigate carbon emissions. Effective participation in global climate policy agreements is crucial to address this pressing issue and ensure a sustainable future for both Africa and the world.

In this context, scholars have conducted extensive research on the influence of FD on economic growth in the continent, but there is a notable gap in the literature when it comes to considering environmental perspectives. Additionally, previous investigations into the environmental consequences of financial development often relied on a single indicator, which may not comprehensively capture the multifaceted nature of this relationship. In an attempt to overcome this limitation, Acheampong (2019) employed six distinct FD indicators to evaluate their influence on carbon emissions. Nevertheless, individual indicators might not fully encompass the intricacies of the financial structure due to their potential shortcomings in depth, accessibility (Emenekwe et al., 2022). Also, past research on globalization's environmental impact in Africa often emphasized economic aspects, using trade openness as an indicator (Acheampong et al., 2019; Gyimah et al., 2023). However, globalization encompasses a broader array of dimensions, necessitating consideration of these factors in environmental analyses. Moreover, prior studies have often failed to account for the moderating impact of globalization and FD on carbon emissions in African nations, resulting in conflicting findings. Thus, this study aims to examine their influence, considering linear and nonlinear relationships, and their potential as moderators in carbon emissions in Africa.

To accomplish our research objectives, we have put out four hypotheses that require testing: (1) Does FD and globalization exhibit linear and nonlinear effects on carbon emissions? (2) Do FD and globalization moderate carbon emissions effect of growth? (3) Is "the Environmental Kuznets's Curve (ECK) hypothesis" valid? and (4) Is there a specific threshold level of globalization and FD that reduce carbon emissions in African nations?

The contribution of this study is twofold. Firstly, our study employs a FD index created by the International Monetary Fund (IMF), rather than relying on a single FD indicator. This index comprises nine distinct metrics that collectively measure the depth, accessibility, and efficiency of FD. Each of these metrics captures specific attributes of financial markets and institutions. Secondly, instead of solely using trade openness, the study employs the KOF Globalization Index (Dreher, 2006), which categorizes globalization into economic, social, and political dimensions, providing a more comprehensive perspective. Thirdly, this research represents a groundbreaking endeavor as it investigates both the linear and nonlinear impacts of FD and globalization on carbon emissions. Moreover, it delves into the moderating role of FD and globalization within a comprehensive panel dataset covering 52 African countries over the period from 1997 to 2021. Lastly, the study's findings yield essential policy recommendations, encouraging African governments to consider the interconnectedness of financial development, globalization, and environmental sustainability. The remainder of the study is structured as below: Section 2 discusses relevant literature, Section 3 outlines the methodology and data sources, Section 4 presents the empirical findings and initiates discussions, and finally, in Section 5, we conclude the paper by offering policy recommendations.

2. LITERATURE REVIEW

2.1. Economic Growth and CO_2 Emission

The role of economic growth on emissions is a complex and contentious issue in the scholarly literature. Some studies suggest that carbon emissions increase or decrease proportionally with economic growth (Acheampong, 2019; Barassi and Spagnolo, 2012; Li et al., 2022; Shikwambana et al., 2021). However, other have found nonlinear relationships, indicating that the relationship between the two variables is complex (Grossman and Krueger, 2010; Rahman et al., 2022; Sohag et al., 2019).

Theoretically, the growth emissions nexus has been extensively studied using the "Environmental Kuznets Curve (EKC)." The EKC was first developed by Grossman and Krueger (1991) and is widely regarded as a valuable tool for understanding this relationship. The EKC assumes an inverted U relationship, which states that as economic growth increases, carbon emissions increase to a certain point, decreasing again. The EKC explanation encompasses three crucial effects: Scale, Composition, and Technique. According to the Scale effect, the early stages of economic growth require more resources and inputs to enhance production. This heightened demand consequently leads to increased energy consumption, greater pollution levels, and elevated carbon emissions. In contrast, the Composition effect underscores the transformation that unfolds within the structure of production as an economy expands. This transformation encompasses a shift from both polluting and less polluting activities. This, in turn, has an ambiguous effect on the environment. Finally, Technique Effect comes into play as countries' income levels increase, resulting in a shift towards a more significant share of the service sector and a decrease in heavy industry output. High-income economies also engage in more research and development, which leads to cleaner technologies and processes that help to reduce carbon emissions.

Following Grossman and Krueger (1991), several empirical studies (see, e.g. Bilgili et al., 2016; Grossman and Krueger, 2010; Rahman et al., 2022; Syed and Tripathi, 2018; Ulucak and Bilgili, 2018) have supported the notion that there is a bell-shaped association between growth and emissions, with pollution "reversing" above a certain income threshold. In general, the EKC theory concludes that environmental problems can be solved through economic growth. While several studies support the EKC hypothesis, others also question it. Some studies have found a linear relationship even after nations achieved a high income level (Onofrei et al., 2022). Others have found that the relationship is not linear but takes a U-shaped (Sohag et al., 2019) or N-shaped form (Maduka et al., 2022).

Also, there has been a noticeable increase in academic research focusing on exploring the link between economic growth and carbon emissions in various African countries, with diverse findings and conclusions emerging from this scholarly discourse. One significant contribution to this ongoing scholarly discourse comes from the work of Alaganthiran and Anaba (2022) who conducted a recent study focusing on Sub-Saharan African countries. Their research, encompassing data from 20 countries spanning the years 2000 to 2020, revealed a noteworthy positive correlation between economic growth and carbon emissions. Also, Espoir et al. (2021) examined 47 African countries from 1995 to 2016, uncovering various patterns, including unidirectional and bidirectional relationships between growth and emissions. Olubusoye and Musa (2020) expanded the inquiry to 43 African countries from 1980 to 2016, finding a positive correlation in 79% of the studied nations. Additionally, Yameogo et al. (2021) explored 20 Sub-Saharan African nations, indicating a decrease in carbon emissions between 2002 and 2017. Conversely, Ouoba (2017) found no significant correlation between growth and emissions in eight West African nations from 1970 to 2010, as per the bound test and Autoregressive Distributed Lag (ARDL) results.

Regarding the EKC hypothesis, numerous studies have explored its applicability in various African countries, yielding diverse findings. In this regard, Maduka et al. (2022) conducted research in Nigeria using ARDL, quartile regression, and the Granger causality test approach. Their study identified an N-shaped association between economic and emissions during the period from 1990 to 2020. In support of the EKC hypothesis, Kwabena et al. (2017) found evidence in Sub-Saharan Africa (SSA), while Al-Mulali et al. (2016) discovered supporting evidence in Kenya. Conversely, Acheampong (2019) and Zoundi (2017) and Twerefou et al.(2016) were unable to confirm the ECK hypothesis in their respective studies for SSA and Ghana.

2.2. Financial Development and CO_2 Emissions

With growing concerns about climate change, the link between FD and carbon emissions is now being increasingly acknowledged. However, scholars disagree on the nature of this relationship. Two conflicting theories can be found in the literature, leading to an ongoing debate. The first theory asserts that FD increase carbon emissions. This theory is based on the premise that a more advanced financial system can facilitate companies' access to capital and credit (Levine, 1997). This, in turn, can lead to more investment in energy-intensive industries that rely heavily on carbon-emitting technologies (Bui, 2020). Also, a sound financial development system can create economic growth and optimism, increasing investment in energy-intensive sectors (Sadorsky, 2010). Additionally, the expansion of industries and urbanization, known for their high levels of carbon emissions, can be facilitated by financial development (Gokmenoglu et al., 2015; Shahbaz and Lean, 2012).

A second theory asserts a FD decrease carbon emissions. According to proponents of this theory, FD can incentivize the growth and widespread use of renewable energy sources and green technologies (Dong and Akhtar, 2022). Furthermore, it enhances the accessibility of low-cost financing for individuals and companies researching and developing environmentally friendly products (Tamazian et al., 2009). FD is also essential for fostering innovation and investment and highlighting the significance of well-functioning financial markets (Mansour, 2023). Moreover, effective financial development can catalyze sustainable development and contribute to reducing carbon emissions. By promoting credit availability, attracting foreign direct investment (FDI), ensuring robust corporate governance, and facilitating technology transfer, the financial system can also help minimize economic activities' environmental impact (Acheampong, 2019; Golub et al., 2011).

Recent empirical research on FD and carbon emissions also yields contradictory and inconsistent results. While studies (see; Shoaib et al., 2020; Zaidi et al., 2019) argue for an adverse relationship, indicating that as financial development increases, carbon emissions decrease, others (Le and Ozturk, 2020) suggest a positive relationship. Furthermore, certain studies, such as (Acheampong et al., 2019; Habiba and Xinbang, 2022), present mixed results, showing both positive and negative associations, while others, like Jamel and Maktouf (2017) find an insignificant relationship between the two variables.

In the context of Africa, several studies have investigated the relationship between FD and carbon emissions. For instance, Odhiambo (2020) conducted an exploration of this relationship across 39 sub-Saharan African (SSA) countries using the GMM spanning from 2004 to 2014. The findings unveiled a substantial and unconditional impact of FD in reducing carbon emissions within the studied region. However, Acheampong (2019) provided a more intricate perspective on the region using a similar methodology. Their study, which encompassed the period from 2000 to 2015, yielded mixed findings. While certain aspects indicated positive impacts of FD on carbon emissions reduction, others demonstrated a decrease in emissions. Additionally, specific financial indicators did not exhibit a significant influence. Moreover, the study's findings did not lend support to the presence of an EKC hypothesis in the region.

Tsaurai (2019) explored this relationship specifically within West African countries, employing pooled ordinary least squares (OLS), fixed effects, and random effects methods, with data spanning from 2003 to 2014. The author found that only domestic financial sector credit was linked to a substantial increase in carbon emissions within the region. Shahbaz et al. (2011) also found a negative long-term effect of FD on South Africa's carbon emissions from 1965 to 2008.

In general, it is evident that the issue of FD impact on carbon emissions in Africa is complex and requires further study. Studies have yielded contradictory results, which may be attributable to the context, indicators, and country-specific characteristics. In the literature, the work of Acheampong (2019) shows a comprehensive approach, analyzing both the "direct and indirect" effects of FD on carbon emissions in SSA nations. However, this study has limitations, including its reliance on aggregated data and its focus on a specific region, which may not be applicable to another region.

2.3. Globalization and CO_2 Emissions

Globalization is an intricate phenomenon involving the increasing interconnectedness and integration of economies, societies, cultures, and governments worldwide (Gygli et al., 2019). It encompasses multiple dimensions, including social, economic, and political factors. This process has paved the way for the unrestricted flow of goods, services, and information across international borders, as well as the widespread diffusion of technology and knowledge. Thus, it has spurred greater levels of innovation and contributed to economic growth (Gallagher, 2009; Zerrin and Yasemin, 2018). However, as economies grow and industries expand due to globalization, concerns have emerged about its effect on the environmental quality (Huo et al., 2022).

The discussion surrounding this issue revolves around two key theories: The "pollution halo" and the "pollution haven." The "pollution halo" hypothesis suggests that through globalization, international organizations can transfer greener technology and management practices to host countries (Gyamfi et al., 2022). This technology transfer includes eco-friendly remedies like pollution reduction and renewable energy technologies, which may effectively decrease carbon emissions. On the other hand, the "pollution haven hypothesis" presents a contrasting view. It suggests that globalization may lead to a phenomenon where industries with high pollution levels relocate their operations to developing countries with less stringent environmental regulations (Bekun et al., 2023). The motivation behind this relocation is often driven by the desire to maintain competitiveness and reduce operational costs. However, the consequence of this movement can be detrimental to the environment in the host countries. These nations, with weaker ecological laws and enforcement mechanisms, may experience environmental degradation and an increase in carbon emissions (Zhang and Wang, 2021).

Empirical studies examining the relationship between globalization and carbon emissions have also significantly drawn upon these hypotheses, but they have produced divergent and conflicting results. For instance, Mehmood and Tariq (2020) focused on South Asian countries and examined this relationship spanning from 1972 to 2013. Employing advanced techniques such as the Autoregressive Distributed Lag (ARDL) and the Unrestricted Error Correction Model (UECM), the authors found that Afghanistan, Bangladesh, Nepal, and Sri Lanka exhibited a U-shaped relationship. However, in Bhutan and Pakistan, the association took on an inverted U-shaped pattern. Similarly, Liu et al. (2020) utilized a semi-parametric panel model spanning 1970 to 2015 to explore the relationship among G-7 countries and identified a U-shaped pattern. On a broader scale, Bu et al. (2016) embarked on an investigation encompassing 166 countries from 1990 to 2009, deploying the KOF globalization index. Their results indicated that carbon emissions tended to rise with higher levels of social, economic, and political globalization in non-OECD member countries, while the impact was found to be insignificant for member countries.

In contrast, You and Lv (2018) conducted an investigation utilizing a spatial panel model, encompassing data from 1985 to 2013, to assess the repercussions of economic globalization on carbon emissions across 83 countries. Their research brought to light the adverse impact of economic globalization on carbon emissions, accompanied by the revelation of emissions' spillover effects on neighboring nations. In a parallel vein, Audi and Ali (2018) examined this relationship within the MENA region, employing the panel ARDL approach spanning from 1980 to 2013. Their findings yielded a divergent perspective, indicating that globalization had a positive influence on environmental quality by curbing carbon emissions in the region. Shifting the focus to BRICS countries, Haseeb et al. (2018) further delved into this nexus, employing dynamic, seemingly unrelated regression and the Dumitrescu-Hurlin causality technique, covering the years from 1995 to 2014. Their findings indicated that globalization had an insignificant effect on the region.

In the African context, Shahbaz et al. (2016) employed the ARDL and PMG techniques to investigate this relationship. Their findings indicated that globalization reduces the concentration of carbon emissions across the continent, albeit with varying outcomes among individual nations. Acheampong et al. (2019) examined this association in 46 sub-Saharan African (SSA) countries between 1980 and 2015, using trade openness as a proxy for globalization. Their analysis led to the conclusion that globalization significantly reduces carbon emissions in the region. In contrast, Kwabena et al. (2017) concluded that globalization contributes to an overall decline in the environmental quality of SSA countries, highlighting the complex nature of the globalization-environment relationship in Africa.

2.4. Comment and Research Gap

A comprehensive review of the existing literature above reveals several key insights and research gaps. Theoretical studies indicate that these factors can have both positive and negative effects on carbon emissions, with the overall impact depending on the magnitude of these effects. However, empirical research shows that the relationship varies depending on factors such as the sample, period, variables, and estimation methods used. However, significant limitations persist in current literature. Firstly, most studies focus on specific regions or countries, neglecting an African perspective. Secondly, the environmental impacts of globalization and financial development, which may be nonlinear or asymmetric, are often overlooked, potentially biasing results. Thirdly, limited scientific evidence substantiates how globalization and financial development can moderate economic growth while reducing carbon emissions. Finally, different methods, samples, and data have made it hard to compare the research of various scholars. Therefore, by addressing these research gaps in this study, a more comprehensive understanding of these relationships may be reached, which will benefit the aims of sustainable development and provide direction to academics and policymakers.

3. METHODOLOGY

3.1. The Model

This study adopts Grossman and Krueger (1991) framework to explore the link between economic growth and carbon emissions. Initially, emissions rise with economic growth and energy consumption but eventually decline after an income threshold is reached. Nevertheless, this relationship is also influenced by other significant factors, such as financial development and globalization. FD can either increase emissions by promoting energy-intensive consumption or reduce them by facilitating investments in cleaner technologies (Zafar et al., 2019; Zhang, 2011). Globalization also notably affects carbon emissions (Le and Ozturk, 2020; Mehmood and Tariq, 2020). On one hand, globalization can stimulate emissions through foreign investments and trade (Tiba and Belaid, 2020). On the other hand, it can lead to cleaner technology transfer, resulting in more efficient production processes and lower emissions (Zafar et al., 2019). Additionally, globalization allows countries to specialize in eco-friendly products using environmentally friendly technologies, further reducing emissions (Shahbaz et al., 2015). Therefore, we extends Grossman and Krueger (1991) model by incorporating of financial development and globalization variables into the carbon emissions function as follows;

$$CO_2 = f\left(ECO, ECO^2, EC, FD, GLOB\right) \quad (1)$$

Where, CO_2 represent carbon emission; ECO is economic growth; EC indicates energy consumption; FD shows financial development; GLOB stands for globalization.

To mitigate potential issues stemming from heteroskedasticity and multicollinearity, the study employed a natural logarithmic transformation for all variables, thereby enhancing the robustness and precision of the results (Le and Ozturk, 2020). It also applied a dynamic reduced-form modeling approach inspired by Acheampong (2019), to examine the linear and nonlinear effects of globalization and FD on carbon emissions. The empirical equation is as follows:

$$lnCO_{2i,t} = \beta_1 lnCO_{2i-t} + \beta_2 lnECO_{i,t} + \beta_3 lnECO_t^2 + \beta_4 lnX_{i,t} + \beta_5 lnFD_{i,t} + \beta_6 lnFD_t^2 + \beta_7 lnGLOB_{,t} + \beta_8 lnGLOB_t^2 + v_i + \varepsilon_{i,t-1} \quad (2)$$

Where $\beta_1 ... \beta_8$ represents coefficient values, and as v_i and $\varepsilon_{(i,t-1)}$ represent the intercepts of the time effect and lagged value of CO_2 emission, respectively, that vary across country $-i$ at time t.

To investigate the moderating effect, we follow Acheampong (2019) work and adjust equation (2) by incorporating the interaction of "financial development and economic growth" ($lnFD_{i,t} \times lnECO_{i,t}$), and globalization and economic growth ($lnGLOB_{i,t} \times lnECO_{i,t}$). Thus, the final estimation of this model is defined as:

$$lnCO_{2i,t} = \beta_1 lnCO_{2i-t} + \beta_2 lnECO_{i,t} + \beta_3 lnECO_t^2 + \beta_4 lnX_{i,t} + \beta_5 lnFD_{i,t} + \beta_6 lnFD_t^2 + \beta_7 lnGLOB_{i,t} + \beta_8 lnGLOB_t^2 + \beta_9\left(lnFD_{i,t} \times lnECO_{i,t}\right) + \beta_{10}\left(lnGLOB_{i,t} \times lnECO_{i,t}\right) + v_i + \varepsilon_{i,t-1} \quad (3)$$

Where represents individual units ranging from 1 to 52, t represents periods ranging from 1997 to 2021, X denotes a set of control variables, v signifies the individual effects, and ε represents the stochastic error term.

3.2. Data

The study utilizes data from 52 African nations, as detailed in Appendix 1, spanning the time frame of 1997 to 2021. The selection of countries and time were guided by data availability. The study measures carbon emissions (kt), economic growth (real GDP per capita growth rate), energy consumption (kg of oil equivalent per capita), and population size (total population), all sourced from (World development indicators, 2021).

Globalization is assessed using the KOF Globalization Index, considering "economic, social, and political dimensions" (Gygli et al.,2019). Each dimension is rated on a scale of 1-100, with higher values indicating greater globalization. The economic dimension includes trade openness, foreign direct investment, and economic integration. The social dimension covers interpersonal interactions, access to information, and cultural exchange. The political dimension examines political connections, international organization membership, treaty participation, and embassy numbers. Financial development is evaluated using the IMF's Financial Development Index, incorporating financial institutions and markets ranging from the minimum value of 0 to maximum value of 1 (Svirydzenka, 2016). FI comprise banks, insurance companies, mutual funds, and pension funds, while FM encompass stock and bond markets. Table 1 provides a summary of the variables utilized in this study, along with their symbols, measurements, and data sources.

3.3. Estimation Technique

Panel data estimation is appropriate for this analysis because it can efficiently utilize both cross-sectional and time-series variations, resulting in more precise estimates (Arellano and Honoré, 2001). The panel provides a more accurate analysis by controlling unobserved heterogeneity specific to each unit. Panel data models also capture dynamic relationships over time, effectively address endogeneity concerns, offer increased degrees of freedom, and allow for testing heterogeneity and interactions (Yameogo et al., 2021).

The study avoids using pooled OLS, fixed effect models (FE), and random effect models (RE) as estimation techniques. This decision stems from the limitations of these models in effectively addressing endogeneity issues that arise from the correlation between regressors

Table 1: Variables, symbols, measurements, and sources

Symbol	Variable description	Measurement	Source
CO	CO_2 Emission	Kiloton	WDI
ECO	Economic Growth	GDP per capita growth (%)	WDI
ENC	Energy Consumption	kg of oil equivalent per capita	WDI
POP	Population Growth	Total population (in millions)	WDI
FD	Financial Development	(0=Lowest, 1=Highest)	IMF
FM	Financial Market	(0=Lowest, 1=Highest)	IMF
FM	Financial Institution	(0=Lowest, 1=Highest)	IMF
GLOB	Overall globalization	(1=Lowest, 100=Highest)	KOF
ECONGLOB	Economic globalization	(1=Lowest, 100=Highest)	KOF
POLGLOB	Political globalization	(1=Lowest, 100=Highest)	KOF
SOCGLOB	Social globalization	(1=Lowest, 100=Highest)	KOF

and the error term in panel data analysis (Amuakwa-Mensah and Adom, 2017). Pooled OLS, FE, and RE models may also be prone to omitted variables bias and have difficulty in accurately estimating the effects of time-invariant variables or unobserved individual-specific effects. The explanatory variables may also suffer from possible endogeneity in these models (Abid, 2017; Judson and Owen, 1999).

In panel data analysis, the "Generalised Method of Moments (GMM)" estimators are frequently utilized to surmount these limitations (Arellano and Honoré, 2001; Blundell & Bond, 1998). GMM estimators employ "instrumental variables" that are correlated with the regressors but uncorrelated with the error term, effectively controlling for endogeneity and producing consistent estimates. Incorporating lagged dependent variables as an internal instrument, GMM also captures dynamic relationships in panel data (Roodman, 2009). This enables the model to account for the persistence and time-varying character of the investigated variables, thereby increasing the precision of estimates. Moreover, GMM estimators are practical and resistant to the overidentification of instruments. They utilize the orthogonality conditions between instruments and the error term to achieve consistent and efficient estimates. This helps mitigate the problem of biased and inconsistent results that can arise from endogeneity in the data. Additionally, GMM can account for heteroscedasticity, which is the presence of different variances across observations. By incorporating weighting schemes or transformation techniques, GMM estimators can provide reliable estimates even in heteroscedasticity.

The difference GMM developed by Arellano and Bond (1991) estimator has the advantage of controlling endogeneity issues using "lagged differences of the dependent variable as instruments." It also eliminates fixed effects and captures the dynamics of the variables in dynamic panel data models. However, the difference technique assumes strict exogeneity, and the number of periods (T) is sufficiently large relative to the number of individuals (N) (Blundell and Bond, 1998). When the number of periods is limited, the instrument set used in the estimator may become weak or invalid. The GMM estimator relies on valid instruments to control endogeneity. Instruments are often constructed from lagged variable differences in dynamic panel data models. With a small T relative to N, there may need to be more variation in the lagged differences to construct valid instruments. As a result, the GMM estimator's ability to control endogeneity may need to be improved, leading to biased and inconsistent parameter estimates. The System-GMM, a more advanced version of the "Difference GMM" developed by Blundell and Bond (1998), combines first-differences and "lagged levels of dependent variables as instruments" to address endogeneity in panel data analysis. It offers several advantages over Difference GMM, including more efficient parameter estimates, improved model accuracy by capturing both short-term dynamics (via first differences) and long-term relationships (via lagged levels), and better control of endogeneity by using a more extensive set of instruments (Wooldridge, 2003). Also, system GMM is particularly useful when dealing with panels of $T < N$.

Therefore, the application of System GMM in our study is justified for several reasons. Firstly, the panel consists of more countries (n = 52) than periods (T = 25 years). Second, GMM addresses the issue of cross-country disparity by incorporating cross-sectional dependence into the analysis, thereby assuring a thorough comprehension of the dynamics across countries. Finally, it provides a robust estimate that overcomes the issues of instrumental overidentification and heteroscedasticity, thereby improving the result's reliability and validity (Yameogo et al., 2021).

In this study, the two-stage system GMM estimation method was preferred to the one-stage system GMM because it addresses potential problems related to missing values and improves control over endogeneity and serial correlation. Two-stage GMM also ensures a larger sample size and allows for more reliable estimates and higher precision in panel data analysis (Roodman, 2009). By using different sets of instruments in the first and second steps, the two-step system GMM effectively deals with endogeneity problems. It takes into account the dynamic nature of the data.

The validation of the GMM model used in this study involved thoroughly assessing the identification and exclusion restrictions. These restrictions are critical since they guarantee that the model is correctly identified and that valid estimates are provided. The Hansen statistic was used to assess instrument validity, with a $P < 5\%$ indicating statistical significance. The Hansen test is preferred over the Sargan test for instrument validation because it can withstand heteroscedasticity and autocorrelation, as emphasized by Roodman (2009). Additionally, the study conducted autocorrelation tests for second-order errors, evaluated the joint significance of weak instruments, and examined the

Table 2: Descriptive statistics

Variables	Count	CV	mean	SD	min	max
LnCO	1150	23.677	7.975606	1.889872	2.302585	13.12857
$lnECO_2$	1259	151.074	1.537219	2.322246	−10.82835	9.888521
ECO	1259	412.391	1.718611	7.089718	−50.73415	140.367
lnPOP	1290	10.182	15.8317	1.611926	11.2557	19.16927
lnENC	555	13.257	6.261166	0.8306944	2.260188	8.117767
lnGLOB	1057	5.206	3.861354	0.2012985	3.198673	4.285791
lnFD	1224	172.892	−2.167972	0.6394721	−5.702036	−0.4421569
lnFM	1034	155.714	−4.494749	3.252162	−24.52688	−0.5390081
lnFI	1224	58.447	−1.662515	0.5382416	−5.423772	−.312849
LnECONGLOB	1057	6.466	3.789645	0.2467116	3.175133	4.444884
lnPOLGLOB	1057	8.414	4.017345	0.337863	2.744061	4.523417
LnSOGLOB	1057	9.222	3.665907	0.3385742	2.386926	4.37475

stationarity of the residual term in the regression analysis. These rigorous validation procedures further enhance the robustness and reliability of the GMM model.

4. EMPIRICAL RESULTS AND INTERPRETATION

4.1. Descriptive Statistics

Table 2 presents the descriptive statistics for the variables under consideration. Carbon emissions *(lnCO)* displays a mean of 8% with a standard deviation (SD) of 1.9%. Additionally, the coefficient of variation (CV) is approximately 23.4%, exceeding the mean value. This suggests that carbon emissions in Africa exhibit instability throughout the period of analysis. The SD for the real GDP growth rate (*ECO*), the logarithm of financial development *(lnFD),* financial market *(lnFM),* and financial institutions *(lnFI)* are significantly greter than their respective averages. Also, Africa shows considerable variation in the real GDP growth rate and all financial development indicators, with CV of 412.4%, 172.2%, 155.75%, and 58.4%, respectively. The logarithm of population growth *(lnPOP)* shows an average increase of 15.8% and 10.2% CV. Energy consumption *(lnENC)* in Africa shows volatility with a CV and mean of about 13.4% and 6.3%, respectively. The logarithm of globalization *(lnGLOB)* has a mean value of 3.9% and a coefficient of variation of about 5.2%. In addition, the log values of economic (lnECONGLOB), political *(lnPOLGLOB),* and social globalization *(lnSOGLOB)* in Africa have mean values of 3.8%, 4%, and 3.7%, respectively, with coefficients of variation of 6.5%, 8.4%, and 9.2%.

4.2. Correlation Matrix

Table 3 displays the correlation matrix between carbon emissions and independent variables along with their significance levels. To detect multicollinearity issues, a correlation coefficient below 0.85 is generally acceptable (Jiang and Ma, 2019). Therefore, it appears that the model is free from multicollinearity problems. Additionally, all independent variables, except for ECO, $lnECO_2$, and lnFI, exhibit positive correlations with carbon emissions.

Also, the bivariate regression analysis depicted in Figure 2 reveals a positive correlation between carbon emissions and the primary study variables. It indicates that as carbon emissions increase, there is a tendency for economic growth, FD and global factors to rise as well, suggesting a significant relationship between carbon emission and interested variables in the African context.

The analysis of the CV, correlation, and bivariate regression highlights a strong and interconnected relationship among FD and globalization indicators and carbon emissions. Therefore, it is essential to consider multiple indicators of globalization and financial development rather than relying solely on one indicator for better understanding.

4.3. Effects of Globalization on Carbon Emission in Africa

Following estimataion techiqnique discribed in methodology section, we utilize a two-stage GMM system to address omitted

Table 3: Corelation matrix

Variables	lnCO	$LnECO_2$	ECO	lnPOP	lnENC	lnGLOB	LnFD	lnFM	lnFI	lnECONGLOB	lnPOLGLOB	lnSOGLOB
lnCO	1											
$LnECO_2$	−0.0319	1										
ECO	0.0632	0.346***	1									
lnPOP	0.704***	−0.106*	0.00480	1								
lnENC	0.571***	0.119*	0.0651	0.0481	1							
lnGLOB	0.593***	0.0432	0.0656	0.203***	0.558***	1						
lnFD	0.177***	0.0452	0.0449	0.356***	−0.160**	0.0114	1					
lnFM	0.156**	−0.0761	0.0160	0.274***	−0.216***	0.0394	0.617***	1				
lnFI	0.0171	0.0866	0.0313	0.234***	−0.177***	−0.0575	0.917***	0.409***	1			
lnECONGLOB	0.172***	0.228***	0.118*	−0.210***	0.385***	0.632***	−0.228***	−0.105*	−0.254***	1		
lnPOLGLOB	0.700***	−0.0862	−0.0113	0.729***	0.326***	0.683***	0.267***	0.183***	0.175***	0.0245	1	
lnSOGLOB	0.209***	0.0366	0.0494	−0.356***	0.453***	0.740***	−0.148**	−0.0930	−0.151**	0.564***	0.121*	1

*P<0.05, **P<0.01, ***P<0.00

variables and endogeneity issues existingin the baseline fixed effects model (Appendix 2)[1]. Thus, the Hansen test results verified the instruments' robustness, with p-values exceeding the 0.05 threshold for all estimated models. We also performed misspecification tests to confirm the GMM specification. The results show significant AR (1) in the residuals ($P < 0.05$), but insignificant AR (2) residuals ($P > 0.05$), indicating no higher-order concerns. We further assessed the stationarity of the residuals using the ADF test. The stationary residuals confirm the suitability and goodness of fit for GMM in all models. Finally, we performed a joint F-test to assess the overall significance of the regression model. The significant results ($P < 0.01$) provided strong evidence of the model's adequacy and effectiveness in capturing the relationship between the variables. Thus, our model supports the appropriateness of using the two-stage system GMM for the analysis.

In Table 4, model 1 presents GMM result, wherein globalization indicators are excluded. Conversely, models 2–5 and 6–9 incorporate linear and nonlinear effects of globalization indicators, respectively. Across all models, the coefficient associated with lagged carbon emissions (lnCO) consistently proves a significantly positive value at 1%. The coefficient values range from 0.564 to 0.896, showing a substantial impact of the previous year's carbon emissions on the emissions of the current year. This finding is anline with the conclusin of Acheampong et al. (2019) and Hao et al. (2016). Both studies identified a positive and substantial correlation between past emissions and those of the present. This is probably related to delayed policy effects and technological inertia from prior high-carbon infrastructure. Economic structures such as production processes, investment cycles, and supply chain dynamics may also contribute to sustained emissions from previous years, influencing current emissions patterns.

In all models, economic growth (ECO) consistently shows significant positive effect, ranging from 0.004 to 0.006 on emmsion. This suggests that Africa's growing economy drives up energy demand, mainly from carbon-intensive fossil fuels. Africa also has low energy efficiency, leading to higher emissions per unit of output. Increased traditional manufacturing processes with high energy use further elevate carbon emissions. This finding aligns with Onofrei et al. (2022) and Osadume and University (2021) but contrasts with Liu et al. (2022).

Also, the coefficient of squared Economic growth ($LnECO_2$) significantly negatively affects carbon emissions in most models, suggesting the presence of an EKC hypothesis in Africa. Interestingly, this study's findings contradict the inferences made by Acheampong (2019)and Abid (2016) concerning Sub-Saharan Africa (SSA). Our finding claims that African economies initially worsen environmental degradation due to factors related to poverty, rapid population growth, urbanization, weak governance, resource-intensive practices, and limited technology. However, as economies grow and diversify, environmental awareness increases, and stricter regulations, greener technologies, and sustainable

1 Prior to conducting the system-GMM analysis, the baseline results were estimated using a fixed effect estimator. However, due to space constraints, the outcomes of the fixed-effect estimator are not presented in this section. For detailed fixed effect results, please refer appendix two.

Figure 2: Displays a bivariate regression analysis depicting the relationship between carbon emissions and key variabls

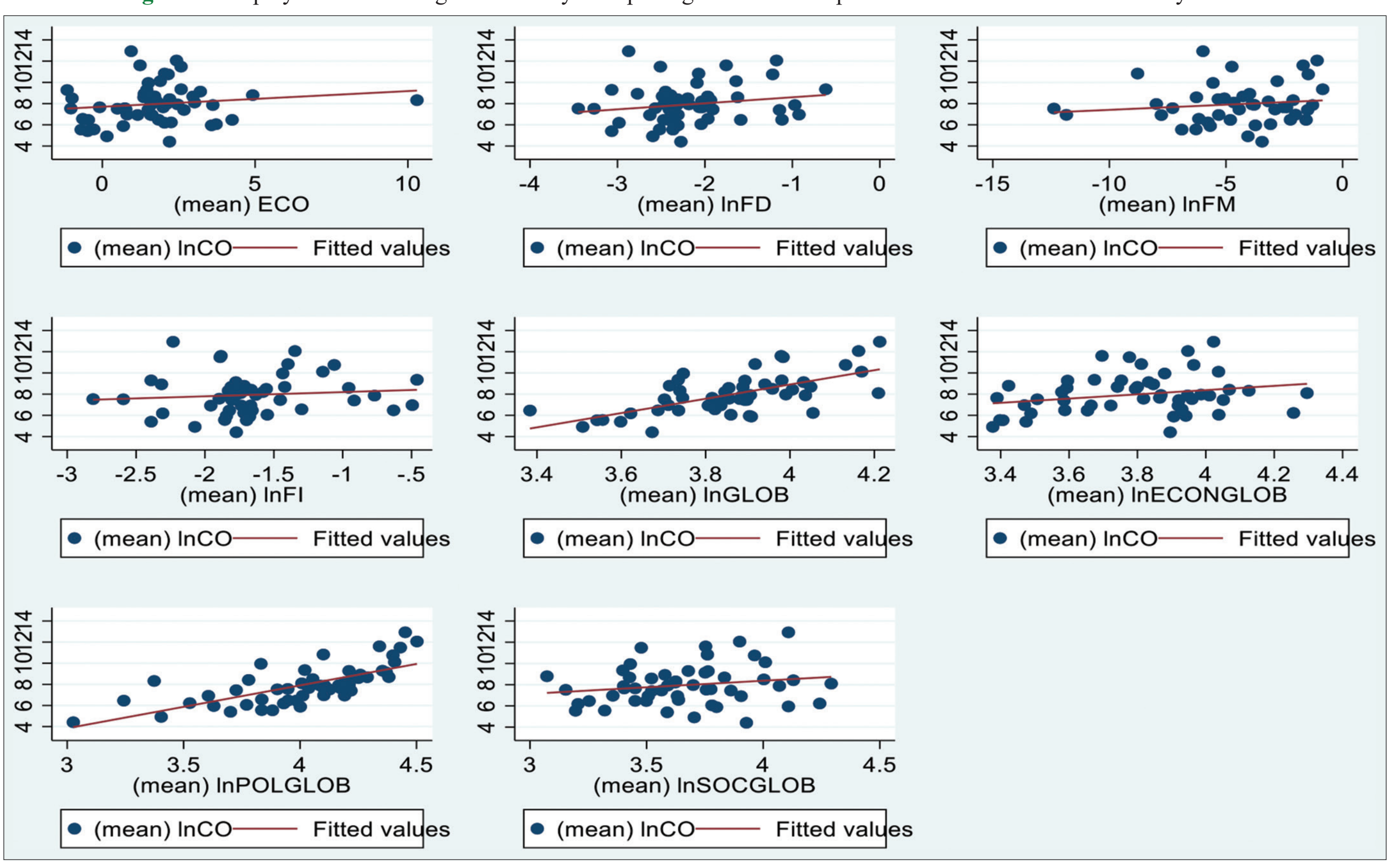


Table 4: Linear and Nonlinear Impact of Globalization and Its Sub-Indices on Carbon Emissions in Africa

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII	Model VIII	Model IX
L.lnCO	0.564***	0.896***	0.778***	0.804***	0.800***	0.764***	0.821***	0.626***	0.802***
	(0.088)	(0.045)	(0.066)	(0.059)	(0.049)	(0.056)	(0.043)	(0.134)	(0.047)
$lnECO_2$	−0.012	−0.007**	−0.015***	−0.010*	−0.007	−0.009*	−0.012***	−0.009	−0.005
	(0.008)	(0.003)	(0.005)	(0.005)	(0.004)	(0.005)	(0.004)	(0.007)	(0.003)
ECO	0.005*	0.004***	0.005***	0.006**	0.005***	0.004***	0.004***	0.006*	0.004***
	(0.003)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.003)	(0.001)
lnPOP	0.306***	0.075**	0.177***	0.104**	0.183***	0.164***	0.126***	0.188*	0.171***
	(0.081)	(0.029)	(0.052)	(0.050)	(0.043)	(0.048)	(0.042)	(0.095)	(0.043)
lnENC	0.514***	0.089*	0.210*	0.198	0.165**	0.207**	0.142**	0.372**	0.194**
	(0.168)	(0.049)	(0.104)	(0.123)	(0.068)	(0.091)	(0.052)	(0.183)	(0.073)
lnFD	0.125	0.043**	0.089	0.092**	0.066**	0.073*	0.092**	0.128*	0.061**
	(0.102)	(0.017)	(0.053)	(0.043)	(0.031)	(0.037)	(0.036)	(0.064)	(0.029)
lnGLOB		0.291**							
		(0.136)							
lnECONGLOB			0.429**				12.462**		
			(0.200)				(4.603)		
lnPOLGLOB				0.228**				−7.632	
				(0.104)				(4.714)	
lnSOGLOB					0.358***				3.126**
					(0.093)				(1.511)
lnGLOB2						0.079***			
						(0.026)			
lnECONGLOB2							−1.589**		
							(0.618)		
lnPOLGLOB2								1.055*	
								(0.621)	
lnSOGLOB2									−0.397*
									(0.208)
Constant	−4.010**	−1.860**	−3.623***	−1.878*	−3.388***	−2.887***	−25.427***	11.654	−8.133**
	(1.631)	(0.797)	(1.256)	(1.038)	(0.883)	(0.872)	(8.393)	(9.452)	(3.099)
Observations	504	460	460	460	460	437	437	460	460
AR (1)	0.007	0.003	0.005	0.005	0.004	0.005	0.008	0.010	0.004
AR (2)	0.152	0.124	0.131	0.130	0.133	0.135	0.179	0.176	0.133
Hansen	27.843	28.901	32.507	32.364	33.143	31.566	27.336	30.607	31.635
P (Hansen)	0.677	0.574	0.442	0.449	0.411	0.488	0.655	0.486	0.485
ADF	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-statics	6508.105	119307.853	15641.764	17741.335	51246.754	19241.081	20944.884	8653.564	28525.513

*P<0.10, **P<0.05, ***P<0.01

practices are adopted. This leads to a decoupling of economic growth and, thereby, carbon reduction.

This study also found that population size *(lnPOP*) in Africa is positively associated with carbon emissions, with a 1% increase in population linked to a 0.075% to 0.306% increase in carbon emissions. This is likely due to a combination of factors, including excessive consumerism, inadequate human capital development, and poverty. Additionally, population expansion leads to higher demand for energy, including fossil fuels, which also contributes to carbon emissions Our findings corroborate prior research by Acheampong (2022), Aye and Edoja (2017), and Dong et al. (2018), which emphasizes the relationship between population size and increased carbon emissions, likely driven by heightened fuel consumption and resource utilization.

Energy consumption *(lnENC)* is a statistically significant positive driver of carbon emissions in Africa in most models. A 1% increase in energy consumption increases carbon emissions by 0.089-0.514%. This is due to the heavy reliance on traditional nonrenewable energy sources, such as coal and oil, which release significant quantities of carbon dioxide when burned. The limited availability of cleaner and more sustainable energy alternatives exacerbates this dependence on carbon-intensive sources, amplifying the overall impact on carbon emissions in the region. Our findings line up Sahoo and Sahoo (2022)and Sarkodie et al. (2019) that have shown that energy use and carbon emissions tend to go hand in hand.

Regarding the impact of globalization, Model 2 reveals a significant positive association between overall globalization (lnGLOB) and carbon emissions. This aligns with Jahanger (2022)'s findings, indicating that a 1% increase in globalization corresponds to a 0.291% rise in carbon emissions. Model 3 further supports this positive effect, specifically for economic globalization (lnECONGLOB), where carbon emissions increase by 0.429% for every 1% increase in economic globalization. Several factors contribute to this phenomenon, with one of the primary drivers being the relocation of polluting industries from developed to developing countries through foreign direct investment. Using outdated technologies, these industries often expand carbon-intensive sectors such as manufacturing and mining. Permissive environmental regulations in African countries often encourage this, leading to higher emissions in these areas. Additionally, the increase in international trade essential to economic globalization requires significant energy use in transportation, further increasing carbon emissions. Our study's results are in agreement with the findings of Xu et al. (2018) but differ from those reported by Shahbaz et al. (2015).

Furthermore, the results from Model 4 demonstrate that a 1% increase in the coefficient of political globalization *(lnPOLGLOB)* corresponds to a substantial 0.228% rise in carbon emissions. Our results align with the findings of Acheampong (2022). Political globalization is primarily measured through government policies. Throughout much of Africa, the absence of effective environmental policy has become a focal concern, intensifying carbon emissions. This regulatory framework deficiency, misaligned incentives, and insufficient emphasis on green technologies contribute to environmental degradation and heightened emissions. Furthermore, Africa has introduced many environmental policies to reduce carbon emissions, but these policies have not been effective due to limited public awareness and inadequate penalties for non-compliance.

In Model 5, social globalization *(lnSOGLOB)* is shown to significantly impact Africa's carbon emissions, with a 1% increase correlating with a substantial 0.358% emissions rise. These results are further reinforced by the work of Jahanger (2022) and support the theory of ecological modernization, suggesting that global norms and cultural practices influence environmental policies and behaviors across nations. This may be related to African countries' environmental awareness and cultural exchange problems. Effective ecosystem management requires understanding human-nature links, which cultural and ecological heritage can provide. However, due to globalization and large-scale migration, Africa faces several cultural problems, such as the loss of a country's native culture and values, a decreased desire for patriotism and nationalism, and a rise in the way of life that doesn't fit with local traditions, all of which contribute to carbon emissions.

Regarding the nonlinear effects, in Model 6, Model 7, and Model 9, overall globalization, economic globalization, and social globalization respectively show a decreasing impact on the rate of carbon emissions, while in Model 8, political globalization demonstrates an increasing influence. Explicitly, a 1% surge in the square of overall globalization *($lnGLOB^2$)*, economic globalization *($lnECONGLOB^2$),* and social globalization *($lnSOGLOB^2$)* causes a respective decrease of 0.079%, 1.5%, and 0.4% in carbon emissions. However, a 1% rise in the square of political globalization *($lnPOLGLOB^2$)* resulted a 10% rise in carbon emissions. These findings suggest that while overall, economic, and social globalization exhibit a concave, inverted U-shaped relationship with carbon emissions, political globalization displays a convex, U-shaped association in the context of Africa.

The existence of the ECK hypothesis in economic can be justified through the Pollution Haven Hypothesis. Initially, In the early stages of economic globalization, African nations may be more likely to attract polluting industries from developed countries. These countries may have weaker environmental regulations and lower labor costs. As a result, these countries may experience increased carbon emissions and environmental degradation. However, as economic globalization progresses, these countries may gain access to cleaner technologies and knowledge transfer, which can help reduce carbon emissions and improve environmental quality. Likewise, because of social globalization, carbon emissions in Africa might experience an initial spike due to heightened international travel, cultural exchange, and increased consumption. However, this trend could gradually reverse over time, as promoting environmental awareness through social media leads to shifts in attitudes and behaviors, ultimately resulting in emission reductions. The exposure to worldwide environmental concerns, combined with the dissemination of sustainable practices through truism and culture exchange, further fosters the adoption of more eco-friendly lifestyles. The validity of EKC hypothesis through economic and social globalization align with Liu et al. (2020) research on G7 countries. Their study highlights globalization's role in fostering environmental consciousness and sustainable practices over time. However, political globalization, in its early stages, may drive African countries to adopt strict environmental regulations and emissions targets to secure aid, reducing emissions. Yet, over time, competition for economic growth through "race to the bottom" can relax regulations, increasing emissions as governments attract investment.

4.4. Effects of Financial Development on Carbon Emissions in Africa

Table 5 presents the impact of financial development, including its sub-indices, on carbon emissions in Africa. In Model 1, there is a notable positive relationship between overall financial development (lnFD) and carbon emissions, where a 1% increase in lnFD corresponds to a 0.026% increase in emissions. This finding is consistent with prior research in the field of developing countries (Hunjra et al., 2020; Khan et al., 2022), highlighting its robustness and alignment with existing conclusions. The positive association may be due to lack of incentives that the financial system provide to firms fro investing in green technologies or to consumers to prefer low-carbon emitting products (like electric cars). Furthermore, in developing countries like Africa, financial development mainly helps small and medium-sized businesses to grow. These businesses typically are on the increasing returns to scale level of output production, and the more they grow the more carbon emission the release.

Also, in model 2, the result shows that the financial market *(lnFM)* has an insignificant impact on carbon emissions. This result contradicts the results of Paramati et al. (2018), who report that the financial market in the form of stocks has a positive and significant impact on carbon emissions. The coefficient of financial institutions *(lnFI)* in model 4 shows statistically significant positive effects on carbon emissions at a level of 10%. Thus, a 1% increase in financial institutions leads to a 0.035% increase in carbon emissions. The observed outcome could be attributed to the challenges faced by African banks and insurance entities to promote the adoption of environmentally friendly technologies, enforce regulations for environmentally focused investments, and provide accessible project financing. These challenges impede investments in environmental sustainability, leading to increased carbon emissions. This finding contradicts

Table 5: The linear and nonlinear impact of financial development and its Sub-Indices on Carbon Emissions in Africa

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII
L.lnCO	0.950***	0.941***	0.862***	0.904***	0.899***	0.636***	0.721***
	(0.018)	(0.019)	(0.063)	(0.045)	(0.070)	(0.105)	(0.069)
$lnECO_2$	−0.003	−0.004	−0.008*	−0.006*	−0.008*	−0.011	−0.014*
	(0.003)	(0.002)	(0.004)	(0.003)	(0.004)	(0.009)	(0.008)
ECO	0.004***	0.004***	0.005***	0.005***	0.005***	0.005**	0.005**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
lnPOP	0.041***	0.045***	0.113**	0.070**	0.087*	0.237**	0.225***
	(0.013)	(0.013)	(0.050)	(0.030)	(0.045)	(0.097)	(0.059)
lnENC	0.030*	0.036	0.130*	0.077	0.055	0.335**	0.200*
	(0.018)	(0.022)	(0.076)	(0.056)	(0.093)	(0.157)	(0.107)
lnGLOB	0.148*	0.154*	0.282*	0.303*	0.285	0.701*	0.711***
	(0.080)	(0.081)	(0.139)	(0.154)	(0.182)	(0.368)	(0.259)
lnFD		0.026**			0.499*		
		(0.010)			(0.295)		
lnFD2					−0.123*		
					(0.064)		
lnFM			0.008			0.147**	
			(0.006)			(0.057)	
lnFI				0.035*			1.151**
				(0.018)			(0.540)
lnFM2						−0.006**	
						(0.002)	
lnFI2							−0.334**
							(0.154)
Constant	−0.952**	−0.922**	−2.442**	−1.856**	−2.391**	−4.934**	−6.052***
	(0.395)	(0.403)	(1.023)	(0.896)	(1.098)	(1.839)	(1.416)
Observations	422	410	378	460	460	378	460
AR (1)	0.002	0.003	0.014	0.003	0.006	0.023	0.009
AR (2)	0.245	0.123	0.118	0.127	0.158	0.131	0.308
Hansen	30.588	28.679	23.945	27.878	28.929	26.455	32.760
P (Hansen)	0.436	0.535	0.813	0.627	0.521	0.699	0.381
ADF	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-statics	419107.549	234040.332	105474.404	121580.774	71818.277	8147.796	9265.069

*P<0.10, **P<0.05, ***P<0.01

the existing literature, including the study conducted by Habiba et al. (2021), which affirms the notion that financial institutions exert an insignificant influence on carbon emissions within developing G20 countries.

Regarding the nonlinear effects, the outcomes observed in Models 5, 6, and 7 underscore a noteworthy trend. These results suggest that both overall financial development and its sub-indices play a significant role in reducing carbon emissions, aligning with the evidence of an inverted U-shaped relationship. These results contradict those of Acheampong (2019), who found that financial development indicators do not have a significant nonlinear effect on carbon emissions in SSA. The presence of an inverted U-shaped association implies that as FD advances beyond a certain point, it becomes increasingly effective in mitigating carbon emissions. This may be due to improved financial mechanisms facilitating investments in cleaner technologies or more efficient resource utilization, ultimately leading to reduced environmental pollution.

In Table 6, Models 1 to 3 focus on illustrating how financial development and its sub-indices moderate carbon emissions. Also, Models 4-7 delve into the moderating effect of overall globalization and its sub-indices indicators on carbon emissions. Model 1 of Table 6 reveals that the interaction of FD and economic growth *(lnFDECO)* shows a significant and negative influence on carbon emissions, with a statistical significance level of 10%. This outcome implies that for every 1% increase in the coefficient of *lnFDECO*, there is an associated 0.022% decrease in carbon emissions. This implies that financial development can improve environmental quality by moderating economic growth. The inference is that financial development encourages transferring traditional green supply chain management approaches and eco-friendly technologies to the African economy, thereby reducing carbon emissions. In addition, it delivers services with reduced investment costs by applying procedures and regulations that foster economic development and thus help to reduce carbon emissions. This finding is contradict with that of Wang et al. (2019) and align with those of Acheampong (2019).

However, the result from Model 2 indicates that the interaction effect of financial market and economic growth *(lnFMECO)* shows positive and insignificant. This may be because the financial sector in Africa does not efficiently allocate resources to environmentally sustainable sectors, thus contributing to increased carbon emissions. Nonetheless, financial development measured by financial institutions *(lnFIECO)* can effectively moderate economic growth and significantly decrease carbon emissions at a 10% significance level in Model 3. This highlights the importance of developed financial institutions in channeling investments towards sustainable projects and promoting adopting green technologies to reduce carbon emissions.

Table 6: The moderating effect of Globalisation and Financial development on CO_2 emission in Africa

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII
L.lnCOt	0.687***	0.765***	0.620***	0.747***	0.779***	0.788***	0.787***
	(0.087)	(0.082)	(0.128)	(0.072)	(0.061)	(0.072)	(0.056)
$lnECO_2$	−0.010	−0.012**	−0.019**	−0.015**	−0.034***	−0.008	−0.009*
	(0.008)	(0.006)	(0.007)	(0.007)	(0.011)	(0.007)	(0.005)
ECO	−0.041	0.011**	−0.030	0.085	0.416**	0.133*	0.072*
	(0.025)	(0.004)	(0.022)	(0.088)	(0.189)	(0.069)	(0.038)
lnPOP	0.192***	0.182**	0.262***	0.164***	0.150***	0.120**	0.193***
	(0.069)	(0.072)	(0.094)	(0.051)	(0.049)	(0.045)	(0.053)
lneENC	0.223**	0.183	0.306	0.156*	0.119	0.183	0.133
	(0.103)	(0.125)	(0.223)	(0.087)	(0.094)	(0.133)	(0.090)
lnGLOB	0.889***	0.542**	1.010***	0.799***			
	(0.285)	(0.235)	(0.306)	(0.221)			
lnFD	0.157*			0.061	0.078	0.058	0.053*
	(0.081)			(0.060)	(0.052)	(0.056)	(0.030)
lnFDECO	−0.022*						
	(0.012)						
lnFM		0.012					
		(0.012)					
lnFMECO		0.001					
		(0.000)					
lnFI			0.098				
			(0.077)				
lnFIECO			−0.023*				
			(0.014)				
lnGLOBECO				−0.020			
				(0.022)			
lnECONGLOB					0.872***		
					(0.309)		
lnECONECO					−0.104**		
					(0.048)		
lnPOLGLOB						0.356**	
						(0.140)	
lnPOLECO						−0.031*	
						(0.017)	
lnSOGLOB							0.589***
							(0.135)
lnsSOECO							−0.017*
							(0.010)
Constant	−4.858***	−4.022***	−6.547***	−4.328***	−4.320***	−2.486**	−4.143***
	(1.624)	(1.377)	(2.168)	(1.091)	(1.309)	(1.035)	(1.090)
Observations	420	378	449	351	351	314	277
AR (1)	0.005	0.015	0.005	0.007	0.003	0.011	0.007
AR (2)	0.234	0.139	0.204	0.182	0.328	0.286	0.190
Hansen	28.258	24.100	27.503	26.556	27.969	29.173	25.378
P (Hansen)	0.346	0.841	0.491	0.433	0.360	0.214	0.279
ADF	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	8029.06	16597.29	6557.30	10912.45	16520.44	12971.92	26295.71

*P<0.10, **P<0.05, ***P<0.01

Similarly, the results derived from Model 4 indicate that the moderating effect of overall globalization (lnGLOBECO) negatively and insiginificat impacts carbon emission. However, Models 5, 6, and 7 lend support to the idea that the moderating impact of economic globalization *(lnECONECO),* political, social globalization *(lnPOLECO),* and social globalization *(lnsSOECO)* significantly contribute to the mitigation of carbon emissions, with statistically significant effects at 10% and 5% levels respectively. This result pioneering endeavor scrutinizing the interplay between globalization and economic growth in environmental dynamics. It offers a fresh perspective on environmental literature and opens new possibilities for utilizing globalization to drive long-term structural changes in economies.

The rationale behind these findings may lie in the hypothesis that well-managed globalization can serve as a catalyst for various positive outcomes. These include the promotion of technological innovation, the elevation of environmental standards, the enhancement of overall productivity through increased trade activity, and the stimulation of economic growth via foreign direct investment and advanced transactions. This, in turn, enables nations to transition their economies into more sophisticated, knowledge-based manufacturing centers, resulting in the production of goods with lower energy-intensive footprints. Embracing global openness emerges as a promising avenue for concurrently improving environmental quality while reaping the desired benefits of structural economic change.

5. CONCLUSION AND RECOMMENDATIONS

This study examines the impact of globalization and financial development on carbon emissions in 52 African countries from 1997 to 2021. It assesses both linear and non-linear effects while considering the moderating role of globalization and financial development in the relationship between economic growth and carbon emissions. Fixed effects and a two-step system-generalized method of moments are used for analysis.

The findings from this study are presented sequentially: Initially, economic growth leads to increased emissions due to energy-intensive activities, but there's potential for emissions to decline as economies advance, aligning with the EKC hypothesis. Population size and energy consumption are significant contributors to carbon emissions. While overall globalization and financial development linearly increase emissions, the squared values of economic and social globalization exhibit an inverted U-shaped relationship, suggesting the potential for globalization to promote sustainability. Financial development, when squared, negatively impacts emissions, aligning with the EKC hypothesis. Moreover, globalization and financial development play crucial roles in moderating the connection between economic growth and emissions, emphasizing the importance of targeted policies and sustainable practices in Africa's development journey. The study's key findings highlight the complex relationship between economic growth, globalization, financial development, and carbon emissions.

In light of the empirical findings, several policy implications are due. First, globalization and financial development have a significant linear impact on carbon emissions in Africa. These trends amplify the scale and intensity of economic activity, resulting in elevated levels of greenhouse gas emissions. To tackle this challenge, African countries need to adopt a multifaceted approach. To counteract the effects of economic globalization, policymakers should embrace a two-pronged strategy. They should incentivize the adoption of cleaner technologies and sustainable practices among industries. Policy makers should also institute stringent environmental regulations to counteract the pollution haven effect. Strengthening domestic governance and fostering international collaborations are vital for managing the emissions impact of political globalization.

Promoting environmental education, community initiatives, and encouraging green consumer choices can mitigate the repercussions of social globalization. Financial development policies should concentrate on embedding sustainability within financial institutions. Pressing green investments and loans through targeted approaches and regulatory frameworks can advance environmentally friendly projects. Additionally, fostering renewable energy development using innovative financial mechanisms can assist in curtailing carbon emissions. Policymakers should prioritize promoting green financing mechanisms and sustainable investment options to mitigate the positive correlation between financial development and carbon emissions. This entails encouraging the adoption of eco-friendly technologies and enforcing regulations that guide financial institutions towards eco-conscious lending practices, thereby mitigating the carbon-intensive consumption patterns attributed to underregulated financial systems.

Secondly, the nonlinear effects of economic and social globalization, financial development, and sub-indices exhibit an inverted U-shaped correlation with emissions. Effective policy interventions must be tailored to facilitate the transition from the initial upward phase of this relationship to the subsequent downward trajectory. To this end, African nations should prioritize attracting investments and technologies that prioritize environmental sustainability during the initial stages of economic globalization. Collaborative efforts should focus on disseminating sustainable practices and technologies, capitalizing on the networks established during the phase of social globalization. Regarding the U-shaped relationship with political globalization, balanced policies are imperative. They should harmonize growth with steadfast environmental regulations, discouraging a "race to the bottom" through international agreements. Additionally, policymakers should foster the development of green financial instruments and enforce regulations that promote sustainable investment.

Thirdly, policymakers can harness globalization and financial development to reshape the interplay between economic growth and carbon emissions. Advanced and cleaner technologies can be propelled by strategically deploying fiscal incentives like tax breaks and grants, in conjunction with emissions regulations. Simultaneously, sustainable supply chain management can be cultivated through mandatory emission reduction standards or voluntary agreements. This momentum towards sustainability gains further impetus by enforcing environmental limits through legislation. Enterprises integrating eco-friendly practices can benefit from incentive programs, while rigorous regulatory frameworks for financial institutions ensure responsible investment. Collaborative partnerships between these institutions and environmentally conscious businesses, supported by joint lending, investment, and research initiatives, expedite the transition towards a greener, more resilient economic future.

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APPENDICES

Appendix 1

Countries	Country codes
Algeria	DZA
Angola	AGO
Benin	BEN
Botswana	BWA
Burkina Faso	BFA
Burundi	BDI
Cabo Verde	CPV
Cameroon	CMR
Central African Republic	CAF
Chad	TCD
Comoros	COM
Congo, Dem. Rep.	COD
Congo, Rep.	COG
Cote d'Ivoire	CIV
Djibouti	DJI
Egypt, Arab Rep.	EGY
Equatorial Guinea	GNQ
Eritrea	ERI
Ethiopia	ETH
Gabon	GAB
Gambia	GMB
Ghana	GHA
Guinea	GIN
Guinea-Bissau	GNB
Kenya	KEN
Lesotho	LSO
Liberia	LBR
Libya	LBY
Madagascar	MDG
Malawi	MWI
Mali	MLI
Mauritania	MRT
Mauritius	MUS
Morocco	MAR
Mozambique	MOZ
Namibia	NAM
Niger	NER
Nigeria	NGA
Rwanda	RWA
Sao Tome and Principe	STP
Senegal	SEN
Seychelles	SYC
Sierra Leone	SLE
South Africa	ZAF
Sudan	SDN
Swaziland (Eswatini)	SWZ
Tanzania	TZA
Togo	TGO
Tunisia	TUN
Uganda	UGA
Zambia	ZMB
Zimbabwe	ZWE

Appendix 2: Baseline result

Table 1: The linear and non-linear effects Globalization on carbon emission in Africa: OLS fixed effects

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII	Model VIII	Model IX
$lnECO_2$	0.00502	−0.000780	−0.000838	0.00114	0.00116	−0.000740	−0.000869	0.000610	0.000864
	(0.00553)	(0.00434)	(0.00440)	(0.00444)	(0.00429)	(0.00434)	(0.00441)	(0.00428)	(0.00429)
ECO	0.000928	0.00277**	0.00280**	0.00259*	0.00246*	0.00279**	0.00277**	0.00229*	0.00233*
	(0.00188)	(0.00136)	(0.00137)	(0.00139)	(0.00135)	(0.00136)	(0.00138)	(0.00134)	(0.00135)
lnPOP	1.633***	1.521***	1.919***	1.931***	1.224***	1.539***	1.915***	1.977***	1.241***
	(0.0892)	(0.127)	(0.0925)	(0.109)	(0.162)	(0.126)	(0.0937)	(0.105)	(0.163)
lnENC	0.437***	0.387***	0.417***	0.440***	0.428***	0.379***	0.419***	0.307***	0.458***
	(0.0795)	(0.0704)	(0.0705)	(0.0714)	(0.0690)	(0.0708)	(0.0710)	(0.0725)	(0.0736)
lnFD	−0.139***	−0.0132	−0.0156	0.0165	−0.0150	−0.0163	−0.0156	−0.0288	−0.00279
	(0.0477)	(0.0489)	(0.0499)	(0.0498)	(0.0485)	(0.0490)	(0.0500)	(0.0486)	(0.0495)
lnGLOB		0.812***							
		(0.177)							
lnECONGLOB			0.330***				0.715		
			(0.0974)				(1.374)		
lnPOLGLOB				−0.0106				−6.214***	
				(0.126)				(1.079)	
lnSOGLOB					0.483***				1.063**
					(0.0925)				(0.493)
lnGLOB2						0.103***			
						(0.0229)			
lnECONGLOB2							−0.0507		
							(0.181)		
lnPOLGLOB2								0.805***	
								(0.139)	
lnSOGLOB2									−0.0880
									(0.0735)
Constant	−20.79***	−21.51***	−26.28***	−25.24***	−15.53***	−20.16***	−26.95***	−13.45***	−16.90***
	(1.484)	(1.662)	(1.504)	(1.550)	(2.348)	(1.835)	(2.831)	(2.528)	(2.612)
Observations	530	464	464	464	464	464	464	464	464
R-squared	0.495	0.699	0.693	0.684	0.703	0.699	0.693	0.708	0.704
Number of ID	37	37	37	37	37	37	37	37	37

Standard errors in parentheses, *** P<0.01, ** P<0.05, * P<0.1

Table 2: The Linear and nonlinear effect of financial development on carbon emission in Africa: OLS fixed effects results

Variables	Model I	Model II	Model III	Model IIV	Model V	Model VI	Model VII
$lnECO_2$	−0.00251	−0.00155	−0.00623	−0.000314	−0.000857	−0.00658	0.00175
	(0.00439)	(0.00430)	(0.00501)	(0.00428)	(0.00428)	(0.00497)	(0.00422)
ECO	0.00160	0.00298**	0.00324**	0.00307**	0.00290**	0.00322**	0.00315**
	(0.00134)	(0.00135)	(0.00144)	(0.00134)	(0.00134)	(0.00143)	(0.00132)
lnPOP	1.457***	1.455***	1.516***	1.394***	1.506***	1.490***	1.405***
	(0.128)	(0.124)	(0.137)	(0.128)	(0.126)	(0.136)	(0.126)
lnENC	0.450***	0.390***	0.339***	0.396***	0.401***	0.293***	0.445***
	(0.0725)	(0.0698)	(0.0742)	(0.0696)	(0.0695)	(0.0757)	(0.0691)
lnGLOB	0.775***	0.689***	0.765***	0.695***	0.669***	0.805***	0.625***
	(0.182)	(0.180)	(0.202)	(0.178)	(0.179)	(0.201)	(0.175)
lnFD		0.842***			1.190***		
		(0.324)			(0.353)		
lnFD2			0.273			0.302	
			(0.234)			(0.232)	
lnFM				0.805***			1.719***
				(0.266)			(0.335)
lnFI					0.0235**		
					(0.00985)		
lnFM2						0.000604***	
						(0.000232)	
lnFI2							0.0568***
							(0.0131)
Constant	−20.69***	−20.06***	−20.60***	−19.19***	−21.06***	−20.07***	−19.78***
	(1.549)	(1.561)	(1.650)	(1.639)	(1.607)	(1.650)	(1.611)
Observations	478	464	382	464	464	382	464
R-squared	0.670	0.704	0.680	0.706	0.708	0.686	0.718
Number of ID	38	37	31	37	37	31	37

***P<0.01, **P<0.05, *P<0.1

Table 3: The moderating effect of Financial Development and globalization on carbon emissions: OLS fixed effects results

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
$lnECO_2$	−0.000632	−0.00951*	−0.00129	−0.000909	−0.00104	0.00134	0.000603
	(0.00434)	(0.00524)	(0.00433)	(0.00436)	(0.00445)	(0.00445)	(0.00430)
ECO	−0.00383	0.0133***	−0.00440	0.00278**	0.0145	0.0199	0.0252
	(0.00767)	(0.00481)	(0.00565)	(0.00136)	(0.0367)	(0.0233)	(0.0162)
lnPOP	1.513***	1.480***	1.516***	1.549***	1.913***	1.922***	1.214***
	(0.128)	(0.136)	(0.128)	(0.152)	(0.0946)	(0.110)	(0.162)
lneENC	0.388***	0.309***	0.394***	0.388***	0.418***	0.450***	0.434***
	(0.0704)	(0.0753)	(0.0706)	(0.0705)	(0.0706)	(0.0727)	(0.0691)
lnGLOB	0.813***	0.856***	0.809***	0.755***			
	(0.177)	(0.196)	(0.177)	(0.247)			
lnFD	−0.00690			−0.0155	−0.0143	0.0181	−0.0119
	(0.0494)			(0.0494)	(0.0501)	(0.0499)	(0.0485)
lnFDECO	−0.00312						
	(0.00357)						
lnFM		−0.0191***					
		(0.00677)					
lnFMECO		0.00120**					
		(0.000547)					
lnFI			−0.00886				
			(0.0460)				
lnFIECO			−0.00485				
			(0.00372)				
lnGLOBECO				0.0445	0.332***		
				(0.134)	(0.0977)		
lnECONGLOB					−0.00297		
					(0.00931)		
lnECONECO						-0.00100	
						(0.127)	
lnPOLGLOB						−0.00425	
						(0.00572)	
lnPOLECO							0.489***
							(0.0924)
lnSOGLOB							−0.00600
							(0.00426)
Constant	−21.37***	−20.26***	−21.44***	−21.92***	−26.19***	−25.19***	−15.42***
	(1.671)	(1.633)	(1.658)	(2.064)	(1.533)	(1.553)	(2.347)
Observations	464	382	464	464	464	464	464
R-squared	0.700	0.689	0.700	0.699	0.693	0.685	0.705
Number of ID	37	31	37	37	37	37	37

***P<0.01, **P<0.05, *P<0.1