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Article

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Interactive Effects of Carbon Dioxide Molecules, Demographic Changes on Financial Development in Sub-Saharan Africa

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ABSTRACT

This study examines the interaction impacts of carbon dioxide molecule emissions and population changes on financial development in Sub-Saharan Africa. The study used yearly time series data spanning the years 2000-2021. Following the PMG and FE results, the dynamic system GMM estimator was used in the study. The study found a significant inverse long-run relationship between carbon dioxide (CO_2) emissions and financial development. Also, demographic changes have a significant positive impact on financial development. The interaction term findings demonstrate that changes in CO_2 and GHG emissions have a negative and significant influence on the impact of the money supply ratio on financial development in SSA. The study suggests policies that support the adoption of financial aid or other incentives for initiatives that reduce CO_2 emissions. Additionally, initiatives to support financial inclusion, uphold financial stability, encourage the expansion of infrastructure, advance social welfare, and ensure environmental sustainability should be made. Therefore, the SSA countries might benefit from their expanding populations to drive long-term economic expansion and improve living standards for their people.

Keywords: CO_2 Emissions, Economic Development, Demographic Changes

JEL Classifications: Q5, E24, G10

1. INTRODUCTION

The financial development of every nation is so sacrosanct in figuring out the nations' economic growth and development which can be inspired by using masses of macroeconomic and environmental conditions consisting of climate changes, differences in demographic locations and gas flaring. CO_2 emission and demographic changes are awesome determinants of the human widespread of residing. The link between financial development and emissions of CO_2 stems from the fact that the former ends in accelerating the manufacturing of goods and services, which contributes to more pollution and degrades the environment (Liu et al. 2022), even as the latter endangered the living conditions of humans. The idea of emission of CO_2 became first documented by Joseph Fourier in 1824 because of the "greenhouse impact," and as a consequence, a Swedish scientist "Syante Arrhenius" related the emission of carbon dioxide with the burning of fossil fuels with a warming effect. However, nearly a century later, American weather scientist James Hansen testified that the "greenhouse gas has been detected and has caused changes in our climates" (Nunez, 2019). In light of this, literature has documented that a well-evolved financial system can supply more credits to households and corporations, with the purpose to help people increase their consumption of goods consisting of automobiles, electronic devices and different family patron goods and this consumption will keep expanding as the financial system keep developing and offer increasingly more credit to the firms as a result, this may, in addition, degrade the environment (Liu et al. 2022).

Carbon dioxide emission causes climate change by using trapping warmness and contributes to respiratory illnesses from smog and air pollutants, a shift in the wildlife populations and habitats, rising seas a and range of other influences (Nunez, 2019). It also causes severe weather, food-chain supply disruptions, and severe greenhouse gas emissions. And the increase in the temperature causes global warming which influences environmental conditions, people's food and water scarcity, weather changes and rise in the sea level (Ali et al., 20189). Noteworthily, the growing average atmospheric temperature has caused global warming, which drives hard and fast adjustments to the Earth's weather and climate changes. Therefore, as people hold to emit toxic greenhouse gases into the environment, it degrades the natural environment and makes residents uncomfortable (Alhorr et al., 2016), and people's dwelling conditions are adversely affected, the streams of earnings, consumption pattern, savings, investment, and transaction motives could be affected. Globally, numerous scholars and academia have broadly studied the links which exist between CO_2 emission, changes within the demography, economic development and financial development of their distinctive paradigms. In the words of Ali et al. (2020), "CO_2 emissions majorly originate from urbanization manner – a dynamic procedure of remodelling rural regions into urban regions with an increase in the number of people and enlargement of the surroundings and equipment". Thus, this constructed environment is anthropogenic. Thus, for this reason, the acceleration of urbanization performs a big function in growing the amount of CO_2 emissions within the demographic environment (Ali et al., 2020).

The sub-Saharan African region is the most liable to the influences of weather change when compared to the rest of the world. A report from the United Nations Fact Sheets on Climate Change as released in Nairobi in 2006 shows that Sub-Saharan Africa is already experiencing about 0.7°C of global warming temperature, with predictions that temperatures will move upward in recent times. Relatedly, the frequency and intensity of drought seem to have worsened African demography and weather. For instance, the water within the big basins of Niger, Lake Chad and Senegal has been extensively reduced by way of 40-60%, which is majorly caused by huge emissions of carbon dioxide. Sub-Saharan Africa accounts for the best two to a few in step with the rest of the world's carbon dioxide emissions from energy generation engines and locomotive assets. According to the World Resources Institute, Africa's position in per capita emissions of carbon dioxide in the 12 months of the year 2000 was 0.8% metric tons per individual, as compared with a worldwide figure of 3.9 tons per annum. Though, African international locations can and are pursuing win-win policies that may limit their greenhouse emissions at the same time as tackling urban pollutants (with its high fitness charges) and introducing solar energy and different innovative and cost-effective technology.

Although strands of literature have made a few contributions on how CO_2 emissions have a direct impact on economic development, none of the empirical studies reviewed have investigated the synergy between carbon dioxide molecules, demographic changes, and financial development, particularly in Sub-Saharan Africa. Previous studies, such as Mardani et al. (2019), investigate the nexus between carbon dioxide (CO_2) emissions and economic growth, whereas Sarkodie (2018), Bekun and Agboola (2019), Akadiri et al. (2019), and Dong et al. (2019) investigate the invisible hand and EKC hypothesis in Africa; electricity consumption and financial increase; carbon emissions, energy consumption, and financial development; and Determinants of global and regional CO_2 emissions. These empirical investigations present conflicting evidence. While some studies indicated a direct and inverse relationship, others reported conflicting results. In light of the current connection, this study adds the following to the body of literature: (a) investigating the impact of carbon dioxide molecules on financial development, (b) examining the impact of population growth on financial development, (c) determining the interactive influence of carbon dioxide omissions on financial development, and (d) determining the interactive influence of greenhouse gas emissions (GHG) on financial development. The knowledge of the relationships between carbon dioxide (CO_2) molecules, demographic changes, and greenhouse gas (GHG) emissions is important. Hence, the understanding of these connections might help financial institutions and policy makers develop policies that support sustainable economic growth in Sub-Saharan Africa (SSA) while addressing environmental and demographic issues.

In light of the preceding explanation, this research differs from prior studies in three respects. First, we examine the influence of population growth on financial development. Second, we account for the impact of greenhouse gas (GHG) emissions on financial development, and third, we examine the interaction influence of CO_2 and GHG on population growth and determine if there is a significant change in its impact on financial development in Sub-Saharan Africa. Recognizing the importance of population growth may enable us to better appreciate the opportunities and challenges associated with financial development in Sub-Saharan Africa. This could broaden policymakers' focus to the importance of improving financial inclusion, promoting investment and savings, aiding in the development of infrastructure, generating employment, and efficiently managing resources in order to take advantage of the benefits of population growth for sustained economic growth. Furthermore, GHG evidence can assist policymakers in addressing GHG emissions through well-crafted financial policies, therefore promoting sustainable financial development in Sub-Saharan Africa. Policymakers may reduce environmental consequences while increasing economic growth by encouraging green financing, improving regulatory frameworks, supporting sustainable development, fostering financial sector innovation, and creating capacity. The rest of the study was structured as follows. Section 2 described the link between CO_2 emissions and demographic trends in Sub-Saharan Africa. Section 3 covers the literature review, while Section 4 discusses data and methodology.

Section 5 presents empirical results and discusses the findings, while Section 6 provides a conclusion, policy implications, and suggestions.

2. CARBON DIOXIDE EMISSIONS AND DEMOGRAPHIC CHANGES IN SUB-SAHARAN AFRICA

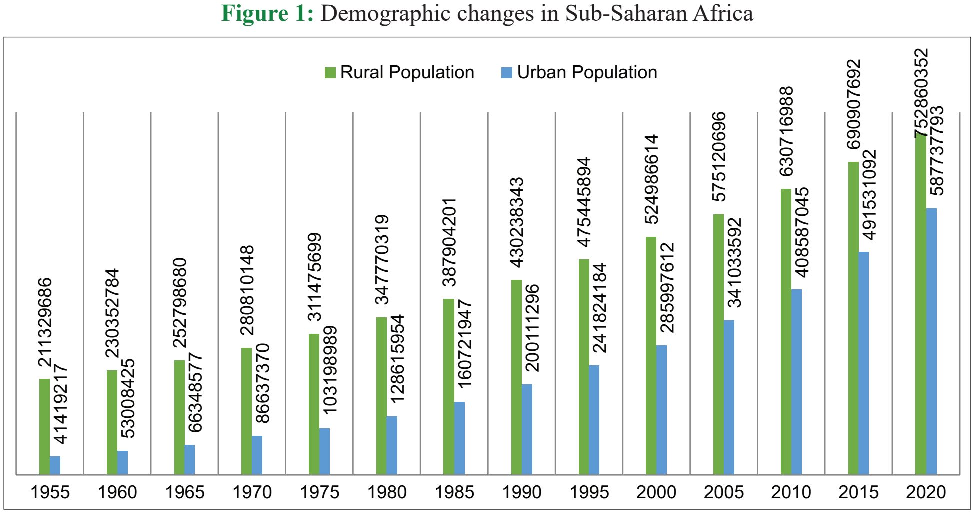
The emissions of carbon dioxide (CO_2) pose a great threat to the surroundings of human dwellings and cause a boom in global warming, which leads to the depletion of the Ozone layer. Noteworthy, the reduction of greenhouse gas emissions has come to be a key climate change mitigation approach that almost every national economies pursue, which is concomitant with the United Nations' zero-tolerance to international carbon dioxide (CO_2) emissions to net-zero by 2050 (IPCC, 2018). Whereas many countries have pursued industrialization so that their financial development will be boosted, the speedy growth of the energy demand for the developed and developing countries however came to be due to a boom in the manufacturing of products and offerings (Quadrelli and Peterson, 2007). Similarly, most African international locations don't have enough water for ingesting, washing, and so on. Many countries are afflicted by pollution from factories, animal, and human wastes in the region. Extra importantly, the Sub-Saharan African region accounts for the smallest percentage of worldwide greenhouse gas emissions – just 3.8%, when compared to 23% of Chinese, 19% of the US, and 13% within the European Union, yet, the continent is mainly vulnerable to climate changes and environmental degradations. Although greenhouse gas emissions across the content constitute a small proportion of the global total, African cities are positioning themselves to invest in low-carbon sustainable development, while working on curbing any form of futuristic climate hazards. This is because they lack the resources to afford goods and services, they need to buffer themselves and recover from the worst of the changing climate effects. Stylized facts from the 2019 CDP data show that 62% of Sub-Saharan African cities have vulnerable to environmental degradation, and many cities and towns experience natural hazardous climate change such as drought, flood, extreme precipitations, rainstorms, and heatwaves (CDP, 2019).

In line with Brooking's record on January 2020, the Sub-Saharan African location is exposed to destructive outcomes of demographic and weather changes, despite their least contribution to international warming, the area is devastating cyclones which affected over 3 million human beings in Mozambique, Malawi and Zimbabwe within the spring of 2018 (Yarnell and Cone, 2019). Consequently, Sub-Saharan Africa has lost a variety of money because of changes in the demography and climate. To tackle the troubles of environmental degradation, greenhouse gas emissions and climate change, Sub-Saharan Africa has spent between $895 billion and $1.4 trillion from 2018 to 2023 – nearly 1/2 of the continent's GDP (Dahir, 2018). Hence, despite the historical carbon emissions narratives in Sub-Saharan Africa, and other macroeconomic conditions, many African countries are making serious efforts to transit to low-carbon emission technologies, low carbon and resilient infrastructures and low-carbon tax structures (Okonjo-Iweala, 2020). Delivering the benefits of a new climate economy requires ambitious action across key economic systems, creating the conditions for the phase-out of coal and rapid scale-up of renewables in the energy sector; investing in shared, electric, and low-carbon transport in cities; scaling up sustainable food and land use systems, including forest landscape restoration; targeting investment to resilient water infrastructure; and reducing emissions from key industrial value chains, such as plastic, automobiles, factories, industries and agricultural activities (IRENA, 2018).

More so, the rate of inter-rural-city migrations in sub-Saharan Africa has increased geometrically, credit to industrialization as well as economic and socio-cultural development. In Figure 1 below, the urban population of Africa is shown. Over 43.4% of the population of Africa resides in urban areas, which accounts for about 567,387,619 people in 2019.

Certainly, the changes in the demography of a place can go a long way in determining the climate change of the region, race or economy. Migration from the rural towns results in the expansion of the number of city dwellers, the construction of new homes,

Figure 1: Demographic changes in Sub-Saharan Africa



Source: Authors' Concept. Graph plotted with data from Credit to Worldometer 2020 industries, and factories, high utilization of gas flaring equipment, water shortage, food shortage, and deforestation (Teye, 2018). As Sub-Saharan Africa least embraces the usage of clean energy assets, carbon dioxide emission has grown to be the order of the day within the region, particularly in the urban areas, due to a couple of reasons including bad energy supply, terrible sources of water, poor hygienic environment, poor per capita income, poverty and insecure living conditions (Teye, 2018). To mitigate this, the United Nations have suggested numerous measures such as the use of clean energy, and regulating gas flaring within the environment for African nations so that the emission of poisonous CO_2 gases can be reduced to the barest minimum.

Relatedly, due to the risky outcomes of inclined demographic changes in Sub-Saharan Africa, financial development was hit hard in recent times. Oil spillage, carbon emissions and gas flaring have brought about harmful results on human beings' financial development. The loss of lives and properties due to oil spillage has left the victims in debilitating opaque economic dangers. Thousands of gas flares at crude oil manufacturing sites globally burned about a hundred forty-four billion cubic meters of gas in 2021. Assuming a "typical" associated gas composition, a flare combustion efficiency of 98% and a Global Warming Potential for methane of 25, each cubic meter of associated gas flared results in about 2.8 kg of CO_2 equivalent emissions, resulting in over 400 million tons of CO_2 equivalent emissions annually (World Bank's Global Gas Flaring Reduction Partnership – GGFR, 2021). Flaring is unproductive and can be avoided far more easily than many other sources of greenhouse gas (GHG) emissions. The gas could be put to good use and potentially displace other more polluting fuels, such as coal and diesel, that generate higher emissions per energy unit.

3. BRIEF REVIEW OF LITERATURE

3.1. Theoretical Evaluation

In recent years, there has been much discussion on the relationship between economic progress and carbon dioxide (CO_2) emissions. Creating effective policies requires an awareness of the connection between financial development and environmental sustainability as economies grow and change. Here, we look into substantial theories that relate financial development to CO_2 emissions. Named after Kuznets (1955) and made popular by Grossman and Krueger (1991), the Environmental Kuznets Curve (EKC) provided empirical evidence for an inverted-U relationship between income levels and environmental quality. This research set the basis for the further adoption and development of the EKC hypothesis in environmental economics and related fields.

According to the Environmental Kuznets Curve (EKC), there is an inverse U-shaped relationship between economic growth and environmental degradation. CO_2 emissions initially increase with an economy's growth because of industrialization and increased energy use. The trend, however, reverses after a certain income level is attained, and sustained economic growth results in advancements in technology, improved laws, and a move toward service-based businesses, all of which contribute to environmental benefits. By providing the necessary funding for green investments and cleaner technologies, financial development facilitates this transition (Edoja et al. 2016). Financial development is crucial for supporting green innovations and sustainable behaviors (Yuxiang and Chen, 2011). Increased access to capital markets and financial institutions can spur investments in renewable energy, energy efficiency, and other environmentally friendly technologies, lowering CO_2 emissions (Zhang and Li, 2022). Well-developed financial markets encourage businesses to embrace CSR initiatives, such as decreasing their carbon impact. Investors are increasingly considering environmental, social, and governance (ESG) aspects when making investment choices, driving businesses to adopt more sustainable practices (Aye and Edoja, 2016). Financial progress frequently results in greater energy consumption owing to increasing industrial and consumer activity, which might initially elevate CO_2 emissions. However, with the right financial tools and regulations, this may be controlled to transition to greener energy sources.

In addition, demographic shifts have significant ramifications for financial development. Recognizing these processes through theories like the Life-Cycle Hypothesis, dependency ratio analysis, and the consequences of urbanization and migration may assist financial institutions and regulators construct sustainable financial systems that accommodate to growing demographic requirements. Effective adaptability to these developments is critical for long-term financial development. The Life-Cycle Hypothesis (LCH), proposed by Franco Modigliani and Richard Brumberg in the 1950s, holds that individuals plan their spending and savings behavior during their lifespan to reach a consistent living standard. While the theory is valuable for understanding saves behavior, it has limitations when applied to financial development. Individuals, according to the LCH, are rational planners who want to maximize their lifetime savings and consumption. However, behavioral economics implies that owing to cognitive biases and short-term thinking, many people do not plan in an organized manner. In developing countries with frequent irregular income and financial shocks, the theory fails to explain income volatility and uncertainty. This restricts its usefulness in forecasting savings behaviour in such situations. Similarly, a low dependence ratio might indicate more savings and investment possibilities. Urbanization increases the demand for different financial services and improves financial inclusion. Migration trends demonstrate the need for remittance services and cross-border financial goods. Considering these demographic changes enables the development of personalized financial solutions to promote economic growth and stability.

3.2. Related Empirical Review

A substantial amount of current research emphasizes how green financing helps reduce CO_2 emissions. Chen et al. (2023) claim that the popularity of green bonds and sustainable investment funds has increased, providing vital funding for eco-friendly technology and renewable energy projects. These financial tools contribute to a decrease in overall carbon footprints and a decreased need on fossil fuels. According to empirical research by Zhang and Li (2022), nations with more advanced financial systems typically make larger investments in clean technology. According to the report, stable financial institutions make it easier for creative green projects to get funding, which eventually reduces CO_2 emissions. The financial markets are essential channels via which investments are directed toward long-term projects. Kapoor and Sharma (2023) found that higher CO_2 emissions were associated with increased market uncertainty. Market volatility and investment aversion are signs of economic insecurity caused by environmental hazards, particularly those posed by climate change. According to Wang et al. (2022), investor attitude has shifted toward sustainable investments as CO_2 levels rise and people become more aware of environmental issues. According to the research findings, investors are increasingly considering environmental, social, and governance (ESG) aspects, resulting in money being reallocated to more environmentally friendly and sustainable financial products.

Liu and Guo's (2023) comprehensive analysis revealed that carbon price stimulates financial innovation in addition to reducing CO_2 emissions. By encouraging the creation of carbon markets and trading platforms, may help integrate environmental concerns into financial decision-making. Research conducted in Sub-Saharan Africa indicates a growing interest in utilizing financial development as a means of mitigating carbon dioxide emissions. For instance, Mwangi and Akinyi (2023) showed how microfinance institutions support small-scale renewable energy projects by utilizing green financing ideas. This trend promotes financial participation and economic advancement in addition to assisting in the reduction of emissions. In Latin America and Asia, similar trends have been seen. Rodriguez and Kim (2022) discovered that financial institutions in specific locations are using green finance strategies, with governments pushing banks to make green loans to assist programs aimed at lowering CO_2 emissions and boosting sustainable development. Dong et al. (2019) discovered that renewable energy can cut worldwide CO_2 emissions, but regions such as South and Central America, Europe, and Eurasia suffer major negative consequences.

Sardkodie (2018) discovered a U-shaped association between environmental deterioration and financial development across 17 nations from 1971 to 2013. Energy consumption, food production, financial development, permanent crops, agricultural acreage, birth rate, and fertility rate all contribute significantly to environmental degradation and pollution in Sub-Saharan Africa. Zhu et al. (2018), on the other hand, discovered that China's CO_2 emissions affect urban population and fuel structure in the short term, but per capita GDP has a favorable influence in the long run. Similarly, Akadiri et al. (2019) discovered a one-way causation from economic growth to energy consumption and from carbon emissions to energy consumption in the long term, but no feedback link was detected. Akadiri et al. (2019) discovered a unidirectional causation from economic growth to energy consumption and from carbon emissions to energy consumption in the long term, but no feedback link was detected. Zhang et al. (2021) investigated the influence of urban transportation infrastructure development on haze pollution through fixed asset investments in public facilities and road areas.

Mutascu (2018) and Lv and Li (2021) discovered a lead-lag link between trade openness and CO_2 emissions in France from 1960 to 2013, with Lv and Li demonstrating a geographical association between emissions and adjacent nations' financial development. Financial development is critical in reducing CO_2 emissions, and being surrounded by highly developed nations can boost environmental performance. Jiang and Ma (2019) showed that financial development boosts CO_2 emissions in developing nations, with varied effects between countries and regions. According to research by Ali et al. (2019) and Saidi and Mbarek (2017), there is a positive short-term association between income and CO_2 emissions, but a negative long-term link since financial development slows down environmental deterioration. As long as the amount of economic development surpasses the edge fee of 0.151, Tariq et al. (2020) discovered that financial development in Pakistan reacts favorably to economic growth. Rahman et al. (2020) investigated the 4-BCIM-EC nations' EKC speculative link between trade openness, GDP per capita, energy usage, and CO_2 emissions.

Islam et al. (2022) reexamines the environmental Kuznets curve theory for Bangladesh, focusing on economic growth and greenhouse gas emissions. The study indicates a positive relationship between economic growth and pollutants, however the EKC only applies to N_2O emissions. According to the report, trade liberalization, urbanization, and financial liberalization do not always enhance the environment, and Bangladesh should invest in renewable energy and reduce GHG emissions. From 1995 to 2018, Vo and Zaman (2020) examine how energy demand influences carbon emissions in 101 different countries. It was demonstrated that while financial development reduces carbon emissions, energy consumption and FDI influx increase them. The findings suggest an income-to-emissions relationship that is inverted U-shaped, with a \$43,500 turning point. The "race to the bottom" concept is prevalent in just 13 countries, with the others also expressing it. According to IAM research, the money supply, foreign direct investment inflows, and energy consumption all contribute to increased carbon emissions. Shoaib et al. (2020) This study examines the link between CO_2 emissions and financial development in G8 and D8 countries from 1999 to 2013. The results show that financial expansion significantly reduces carbon emissions, with trade openness and energy consumption being more pronounced in D8 countries. According to the report, reducing carbon emissions may be achieved through trade-related emissions reduction measures, stricter monetary regulations, and more robust financial institutions. The results suggest that overcoming these obstacles is essential for sustained development.

Bashir et al. (2020) examines the effects of technology, financial development, renewable energy, and environmental taxes on carbon emissions in OECD economies from 1995 to 2015. It finds that although economic development raises emissions, environmental taxes decrease them. By lowering emissions, the use of renewable energy, technological advancements, and financial growth all contribute to improving environmental quality. Investments in renewable energy and long-term growth should be encouraged by policy. Zaidi et al. (2019) investigates the relationship between financial development, globalization, and carbon emissions in APEC countries using the Environment Kuznets Curve. The results show that while financial development and globalization significantly reduce emissions, economic growth and energy intensity increase them. The study also shows how globalization and financial growth feedback on one another, with policy consequences for APEC members. In ten countries in Central and Eastern Europe, Manta et al. (2020) examines the relationship between CO_2 emissions, energy consumption, economic growth, and financial development between 2000 and 2017. The results show that there is a bidirectional causal link between economic growth and financial development and that energy consumption and CO_2 emissions have no long-term impact on economic growth. Financial development increases CO_2 emissions in the short run, which leads to higher energy consumption and economic growth. In the ASEAN-5 countries, Nasir et al. (2019) examines the effects of financial development, FDI, and economic expansion on the environment. It found that these traits and environmental degradation had a substantial long-term association. The Environmental Kuznets Curve was adversely impacted by increases in CO_2 emissions brought about by FDI, economic expansion, and FDI. The results highlight the need for long-term foreign direct investment and inclusive policy.

Ma et al. (2022) examines the impact of demographic shifts and financial growth on the non-hydro renewable energy sector in ten developing and ten industrialized countries between 1990 and 2018. The results show that while bond markets are helpful in developed countries, the stock market and bank intermediaries promote industrial growth. Even though population aging slows industrial progress, foreign direct investment boosts it in emerging economies. Zhou and Ye (2023) investigates how state policies affect the digitalization of inclusive finance among China's older population. The study reveals that among the older population, policy shocks considerably boost inclusive finance digitalization, notwithstanding a negative association. Additionally, the study shows divided social and economic results, with rising real estate investment and falling contentment. Demirgüç-Kunt and Levine (2009) examine how financial development affects the distribution of income while obliquely addressing the purpose of population growth. The authors argue that financial development can help reduce income inequality, which is often made worse by the rapid population growth that occurs in emerging economies. As financial services become more widely available, especially in areas that are expanding quickly, economic prospects improve and overall financial growth is encouraged. As to the research, countries with advanced financial systems are more adept at handling the challenges posed by rapid population growth, diminishing inequality, and fostering equitable economic development.

4. DATA AND METHOD

The study employed yearly time series data from 2000 to 2021. The data was obtained from the World Development Index (WDI) for 53 sub-Saharan African nations. The study used the generalized method of moments (GMM) because of its capacity to deal with endogeneity issues. Hansen (1982) indicated generalizes the technique of moments permit the use of numerous moment conditions, which can increase estimator efficiency and consistency, especially in cases when standard approaches may be ineffective. the link between carbon dioxide molecule emissions, demographic changes, and financial development is first described in functional or economic model, as shown in Eq.1 below.

$$FD = f\,(CO_2, DGC) \tag{1}$$

Financial development (FD) is measure with credit to the private sector (CPS), while carbon dioxide molecules measured with CO_2 emissions in metric tons per capita. As such, demographic change (DGC) is proxied with population growth. Financial development (FD) is assessed using credit to the private sector (CPS), whereas CO_2 emissions are estimated in metric tons per capita. As a result, demographic change (DGC) is measured in terms of yearly population growth. Eq.2 was generated by transforming eq.1 into an econometric model.

$$CPS_{i,t} = \beta_0 + \beta_{1i}\,CPS_{i,t-1} + \beta_{2i}\,CO_{2i,t} + \beta_{3i}\,DGC_{i,t} + \beta_{4i}\,X_{i,t} + \theta_{i,t} + \lambda_i + \mu_{i,t} \tag{2}$$

where $CPS_{i,t}$ also symbolizes a collection of control factors, specifically greenhouse gas emissions (GHG) and financial depth. Financial deepening is measured in this study using a broad money ratio (M2/GDP), as in Manasseh et al. (2024) study. Because GHG emissions are linked to regulatory, physical, and transition concerns that might have an impact on financial stability, examining their impact on the financial system can aid in understanding the possible effects on financial institutions and markets. Similarly, understanding the function of financial deepening helps to create a more dynamic, robust, and inclusive financial system, as well as the financial system's potential to drive long-term economic growth. Furthermore, to determine how changes in CO_2 emissions and greenhouse gas emissions (GHG) affect the impact of financial deepening (M2/GDP), as well as whether changes in CO_2 emissions could worsen the impact of GHG on financial development, Eq.2 was converted into Eq.3 by incorporating the interaction term into the model.

$$CPS_{i,t} = \beta_0 + \beta_{1i}\,CPS_{i,t-1} + \beta_{2i}\,CO_{2i,t} + \beta_{3i}\,DGC_{i,t} + \beta_{4i}\,X_{i,t} + \beta_{5i}\,Interact_{i,t} + \theta_{i,t} + \lambda_i + \mu_{i,t} \tag{3}$$

However, $\theta_{i,t}$ is the time-specific effects, λ_i is the country-specific effects, μ is the error term, t is time index and i is the cross-sectional index.

53 Sub-Saharan African countries for the periods 2000 to 2021 were selected, and they include; Algeria, Angola, Benin Republic, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Chad, Central African Republic, Comoros, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Eswatini, Republic of Congo, The Democratic Republic of Congo, Gabon, Ghana, Gambia, Guinea, Guinea-Bissau, Ivory Coast, Kenya, Lesotho, Liberia, Libya, Madagascar, Mauritania, Mauritius, Malawi, Mali, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Sudan, South Sudan, South Africa, Tanzania, Togo, Tunisia, Uganda, Zambia and Zimbabwe.

Table 1 shows that the mean, median, standard deviation, skewness, and kurtosis values are not too far apart. The findings also indicated that the total variations in the series vary from −6.350065 to 5.149841, representing the series' minimum and maximum values, and that the probability values of the Jarque-Bera statistic for each variable are statistically significant (<0.05). This suggests that the error terms of the variables are normally distributed, and hence the variables are appropriate for assessing the relationships under test. We examined the correlation between the model variables, as indicated in Table 2 below.

Next, we ran a correlation test (Table 2) to see whether there were any relationships between the variables. Notably, Spearman's rank correlation evaluates the degree and direction of the relationship between two ranked variables. It denotes the degree of monotonicity of the connection between two variables, or how effectively it can be represented by a monotonic function. Table 2 demonstrates the existence of weak and negative relationships between the financial development indicator (CSP), CO_2, and DGC. In addition, additional factors such as M2/GDP have positive and negative correlations with CPS, CO_2, and DGC, respectively. As a result, we found that these variables are only moderately associated.

5. EMPIRICAL RESULTS AND DISCUSSION

5.1. Unit Root Test

Finding the stationarity and order of the variables' integration was our first task. We used a variety of unit root tests to achieve this aim, including the Fisher-ADF and Fisher-PP checks suggested by Madala and Wu (1999), the LLC test provided by Levine, Lin, and Chu (2002), and the IPS test suggested by Im, Pesaran, and Shin (2003). The ADF uses parametric autoregression to simulate error structure, but the PP test ignores serial correlation, which is the rationale behind merging the two tests. The results of the unit root test show that certain variables were integrated with I(0), others with I(1), and none with I(2), as shown in Table 3. The alternative hypothesis (no root) and the null hypothesis (unit root) were used in unit root testing. If the probability was less than 0.05, the null hypothesis had to be rejected. Since the variables are stationary, meaning their probability values are <0.05, we found that there are no unit roots in the series and the null hypothesis was rejected for every variable. The unit root test results are displayed in Table 3.

In addition, after testing for a unit root, we extended our investigation to look for the possible existence of cointegration between carbon dioxide molecule emissions, demographic changes, and financial development. In that remark, we used two-panel cointegration tests from Pedroni (2004) and Kao (1999) in Sub-Saharan Africa. Pedroni is our primary test for avoiding ambiguity, but the Kao test is used to assess robustness.

There are seven (7) outputs from Pedroni's (2004) cointegration, which are separated into within- and between-dimensions. Four outputs had been obtained in the within-dimension: panel v-stat, panel rho-stat, panel pp-stat, and panel ADF stat. Three outputs were obtained in the between-dimension - group rho-stat, group pp-stat, and group ADF-stat. The "between dimension" focuses on long-term correlations between variables between nations, whereas the "within dimension" offers details on long-term interactions among variables within the panel. If the probability value in each dimension is less than 0.05, the variables are cointegrated. Because of this, the existence of cointegration in the between dimension indicates that the variables move in tandem throughout time, even in the case of brief oscillations or fluctuations in values across the nations. There are occasions when this long-term connection is seen as evidence of a single underlying structural link with global implications. The within-dimension's substantial cointegration

Table 1: Descriptive statistics

Variable	CPS	CO_2	DGC	M2/GDP	GHG
Mean	3.688	1.228	0.996	0.834	4.147
Median	3.815	1.362	1.126	0.949	4.159
Maximum	4.379	5.149	4.944	4.259	4.503
Minimum	0.309	−2.363	−6.350	−5.604	3.728
SD	0.413	1.590	1.124	1.197	0.152
Skewness	−3.901	0.078	−1.003	−0.929	−0.372
Kurtosis	28.22	2.402	6.680	5.562	2.800
Jarque-Bera	367.2	18.58	556.3	421.5	28.89
Probability	0.000	0.000	0.000	0.000	0.000

Source: Computed by the author. CPS: Credit to the private sector, CO_2: Carbon dioxide, DGC: Demographic change, GHG: Greenhouse gas, SD: Standard deviation

Table 2: Spearman's correlation matrix

Variable	CPS	CO_2	DGC	M2/GDP	GHG
CPS	1.000000				
CO_2	−0.559855	1.000000			
DGC	−0.614231	−0.558439	1.000000		
M2/GDP	0.610748	−0.288983	−0.021591	1.000000	
GHG	−0.354840	−0.722995	−0.027784	−0.026199	1.000000

Source: Computed by the author. CPS: Credit to the private sector, CO_2: Carbon dioxide, DGC: Demographic change, GHG: Greenhouse gas

Table 3: Unit root test results

Variable	LLC	IPS	Fisher-ADF	Fisher-PP	Integration order	
					Level	First difference
CPS	−39.22*** (0.000)	−28.72*** (0.000)	1185.7*** (0.000)	1067.9*** (0.000)	-	I (1)
CO_2	−18.13*** (0.000)	−16.66*** (0.000)	473.9*** (0.000)	501.48*** (0.000)	-	I (1)
DGC	−18.25*** (0.000)	−17.41*** (0.000)	482.6*** (0.000)	609.17*** (0.000)	I (0)	-
M2/GDP	−10.423*** (0.000)	−11.688*** (0.000)	341.4*** (0.000)	598.21*** (0.000)	I (0)	-
GHG	−42.89*** (0.000)	−30.58*** (0.000)	1148.2*** (0.000)	1532.2*** (0.000)	-	I (1)

Source: Author's concept. *, ** and ***Represent the 1%, 5% and 10% significance levels. (.) Represents the *P* values. CPS: Credit to the private sector, CO_2: Carbon dioxide, DGC: Demographic change, GHG: Greenhouse gas

Table 4: Estimated results for cointegration tests

Variable	Pedroni (2003) cointegration test							Kao (1999) test
	Within – dimension				Between - dimension			Robust check
	Panel v-statistics	Panel rho-stat	Panel PP-stat	Panel ADF-stat	Group rho-stat	Group PP-stat	Group ADF-stat	ADF statistics
Model 1	−9.855***	3.208***	−0.791	7.904***	5.369***	−8.419***	9.075***	−3.266***
	(0.000)	(0.009)	(0.214)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Model 2	−7.906***	2.959**	−4.314***	−0.612	5.099***	−2.063**	−1.535	−3.676***
	(0.001)	(0.019)	(0.004)	(0.270)	(0.000)	(0.019)	(0.062)	(0.000)
Model 3	−7.642***	3.614***	0.288	6.608***	5.936***	9.461***	9.022***	−3.002***
	(0.001)	(0.010)	(0.613)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Model 4	−1.961	4.018***	0.809	5.910***	6.335***	0.567	7.772***	−2.783***
	(0.975)	(0.000)	(0.791)	(0.000)	(0.000)	(0.713)	(0.000)	(0.003)

Source: Author's concept. *, **, and ***The level of significance, (.) Represents the probability and decisions are taken based on a 5% level of significance

result demonstrates the long-term relationship between the variables in each nation. This implies that the variables in the panel follow a shared stochastic trend or that there is an equilibrium relationship between them. Thus, the null hypothesis, according to which there is no cointegration, is rejected.

5.2. Panel Estimated Dynamic Generalized Method of Moment - DGMM

Panel dynamic GMM was used to investigate the link between carbon dioxide molecule emissions, demographic changes, and financial development in Sub-Saharan Africa. As indicated in Table 5, we estimated the difference as well as the system GMM. Since GMM uses internal instruments to account for endogenous regressors and provides consistent estimates in the absence of serious exogeneity, it is advantageous for models with lagged dependent variables. However, because system GMM employs more moment conditions, it is more efficient, lessens the impact of weak instruments in difference GMM, and is better suited for smaller sample sizes. System GMM also combines equations in levels and first differences. We analyse the coefficients of the fixed effects (FE) and pooled mean group (PMG) findings to determine which estimator between difference and system GMM is most appropriate. If the coefficient of the FE is greater than the PMG (i.e., FE>PMG), it indicates that the FE is dominant, and the dynamics of the model are important. This suggests that individual units differ in a systematic way (cross-sectional heterogeneity). Because it permits the estimate of coefficients while accounting for unobserved individual-specific effects (like fixed effects) and addressing endogeneity through instruments, the system GMM estimator is better suitable in this situation. However, if otherwise (that is, FE<PMG), then the FE is not dominating and the model's dynamics are not as significant. Because difference GMM is more resilient to weak instruments and concentrates on the differences between the variables, it is therefore more applicable. As a rule of thumb, since the coefficient of the FE is greater than the coefficient of the PMG across all models, the system GMM estimator is better suitable for this investigation. Thus, Table 5 presents the estimated GMM findings.

Furthermore, given that system GMM is the most appropriate estimator, Table 5 (see second column of model 1) shows that CO_2 is significantly associated to credit to the private sector. This simply suggest that a percentage increase in CO_2 omissions significantly cause about 24% increase in credit to the private sector in SSA. Hence, the significant and direct link between CO_2 omission and credit to the private sector relate to environmental Kuznets hypothesis (EKC). According to the EKC hypothesis, as an economy develops, environmental degradation increases up to a certain point (initial phase of financial development) and then starts to decline as the economy reaches a higher level of income and can afford cleaner technologies and stricter environmental regulations. Thus, this finding is consistent with Zhang and Li (2022), Wang et al. (2022), and Liu and Guo (2023) who also found the existence of direct link between CO_2 and financial development, and such supported environmental Kuznets hypothesis. Similarly, increase in financial development leads to increased availability of credit and investment opportunities, which can boost industrial and economic activities as also noted by Sardkodie (2018). These activities can lead to higher energy consumption and CO_2 emissions, particularly if the energy mix relies heavily on fossil fuels. Improved financial systems can facilitate large-scale infrastructure projects, often associated with increased CO_2 emissions during construction and operation phases. This relationship highlights the need for a balanced approach that fosters economic growth while ensuring environmental sustainability. Hence, policymakers, financial institutions, and businesses must collaborate to implement strategies that promote green investments, enforce environmental regulations, and raise public awareness to achieve sustainable development goals. Thus, this evidence is consistent with Islam et al. (2022), Islam et al. (2017), Bashir et al. (2020), Zaidi et al. (2019), Manta et al. (2020), Ali et al. (2019) and Manasseh et al. (2024) studies. However, controlling for the interactive influence of GHG on financial deepening (M2/GDP), we found contradictory evidence (see model 4, column 2). A negative significant relationship between CO_2 emissions and financial development indicates that as credit to private sector progresses, CO_2 emissions decrease. This relationship has several important implications for economic, environmental, policy, and social dimensions.

Population growth is used as a proxy for demographic changes (DGC), and a positive significant link between DGC and credit to the private sector indicates that as population growth rises, so does credit to the private sector (see column 2, model 1). This suggests that a percentage rise in population growth causes the private sector's credit to expand by 42%. The financial industry can expand as a result of a rise in demand for financial services like banking, insurance, and investment goods brought on by

Table 5: Dynamic generalized method of moment estimated results

Variable	Model 1		Model 2		Model 3		Model 4	
	Difference GMM	Sys. GMM	Difference GMM	Sys. GMM	Difference GMM	Sys. GMM	Difference GMM	Sys. GMM
CPS (−1)	−0.251***	0.241***	0.270***	0.399***	0.065***	0.220***	0.293***	0.182***
	[0.022]	[0.053]	[0.004]	[0.111]	[0.012]	[0.078]	[0.085]	[0.097]
CO_2	−0.115	0.539***					−0.056***	−0.109***
	[0.220]	[0.126]					[0.003]	[0.077]
DGC	0.266***	0.418**	−0.088	0.230***	−0.066***	0.411***	0.222***	0.531**
	[0.066]	[0.256]	[0.126]	[0.056]	[0.024]	[0.075]	[0.015]	[0.287]
M2/GDP	0.512***	0.658***	−0.128***	0.552***				
	[0.013]	[0.174]	[0.021]	[0.181]				
GHG	−0.127***	−0.468***			−0.050***	−0.359***		
	[0.016]	[0.103]			[0.010]	[0.069]		
GHG* CO_2			−0.025**	−0.107***				
			[0.010]	[0.060]				
M2/GDP* CO_2					−0.051**	−0.034**		
					[0.021]	[0.015]		
M2/GDP*GHG							−0.019***	−0.138***
							[0.006]	[0.050]
Number of Obs.	1060	1007	1060	1001	1007	1007	1007	1007
PMG	0.649		0.780		0.978		0.309	
FE	0.824		0.924		11.55		0.595	
AR1	−0.352 (0.026)		−0.185 (0.049)		−0.257 (0.069)		0.324 (0.124)	
AR2	0.224 (0.187)		0.409 (0.717)		0.193 (0.262)		−0.260 (0.222)	
Hansen	46.13142 (0.190132)	56.61342 (0.107636)	48.46413 (0.454115)	96.11440 (0.163238)	49.20518 (0.464906)	75.69275 (0.211541)	49.44986 (0.415098)	96.62775 (0.110240)

Source: Author's concept. *, **, and ***Represents %, 5% and 10% significance levels. [.] SE, and (.) is the *P* value. All the variables are in their natural logarithm. SE: Standard error, CPS: Credit to the private sector, CO_2: Carbon dioxide, DGC: Demographic change, GHG: Greenhouse gas, PMG: Pooled mean group, FE: Fixed effects, GMM: Generalized method of moments

population growth. Therefore, an increasing population may result in larger overall savings and investments, which would free up more funds for financial deepening and economic expansion. Even after taking into consideration the combined effect of CO_2 and GHG, this evidence remained consistent (see columns 2 of mode 2, column 2 of model 3, and column 2 of model 4). This indicates that the signs of the impact of population growth on credit to the private sector are unaffected by CO_2 and GHG. The results of this study support the arguments made by Demirguc-Kunt and Levine (2009), who claimed that increased accessibility to financial services leads to an expansion of economic prospects, especially in areas experiencing rapid population growth, which in turn promotes overall financial development.

To determine if increased availability of financial services, including unrestricted access to credit, promotes financial development, we extend our research by accounting for the influence of the money supply ratio (M2/GDP) on credit to the private sector in SSA. The findings in Table 5 demonstrated a significant and direct relationship between the money supply ratio and lending to the private sector. This suggests that a percentage rise in M2/GDP resulted in a 51% increase in credit supply in the SSA. To determine if increased availability of financial services, including unrestricted access to credit, promotes financial development, we extend our research by accounting for the influence of the money supply ratio (M2/GDP) on credit to the private sector in SSA. The findings in Table 5 demonstrated a significant and direct relationship between the money supply ratio and lending to the private sector. This suggests that a percentage rise in M2/GDP resulted in a 51% increase in credit supply in the SSA. Thus, this conclusion is congruent with those of Manasseh et al. (2024). In contrast, it contradicted the idea that financial deepening is adversely connected to growth (Manasseh et al. 2024). Based on the facts presented above, financial deepening is an important driver of Sub-Saharan financial development. This conclusion has significant ramifications for the region's financial system, financial stability, and the SSA economy in general. It helps firms to invest in cutting-edge technology and grow activities, hence increasing efficiency and competitiveness.

Also, we discovered an inverse link between greenhouse gas (GHG) emissions and credit to private sector, implying that as GHG emissions fall, financial development increases, vis-a-vis. As a result, the growth of Sub-Saharan Africa's financial system has the potential to spur more investment in green technology and sustainable practices. This might encourage financial institutions to provide more green bonds, loans for renewable energy projects, and funds dedicated to sustainable businesses, lowering GHG emissions. The interaction evidence reveals that greenhouse gas emissions and carbon dioxide emissions (GHG × CO_2) have a significant and negative long-term impact on credit to the private sector (see column 2, model 2), while financial deepening and carbon dioxide emissions (M2/GDP × CO_2) have a negative long-term impact on credit to private sector (see column 2, model 3). The interaction between GHG emissions and CO_2 emissions significantly influences credit to the private sector in SSA by shaping economic opportunities, regulatory environments, risk assessments, and market dynamics. This can enhance the provision of more credit to businesses that invest in green technologies, that can lower environmental impact of these investments. This can lead to a broader shift towards sustainable industrial practices. Similarly, further research showed that the interaction between financial deepening (M2/GDP) and greenhouse gas (GHG) emissions (GHG × CO_2) has a significant and negative long-run association with credit to private sector (see column 2, model 3). This demonstrates that changes in GHG emissions have a considerable and negative impact on the influence of financial deepening (M2/GDP) on credit to private sector.

The results of AR (1) and AR (2) tests validates the above discussed findings. Hence, the dependability of the estimation is ensured by the AR (1) and AR (2) tests. While AR (2) tests examine second-order autocorrelation in the differenced residuals, they also look at first-order autocorrelation of residuals in the differenced equation, which ensures autocorrelation at the first lag. We also found that the outcome of the AR (2) test is not significant. Hence, the AR (1) test is significant, which is expected. The absence of second-order autocorrelation is confirmed by this outcome, suggesting the accuracy of the estimate instruments. This is important because it implies that the instruments are not sufficiently exogenous, which might compromise the validity of the GMM results. In light of the preceding discourse, it is evident that the obtained results align with the GMM assumptions.

6. CONCLUSION AND POLICY RECOMMENDATIONS

This study investigated Interactive effects of carbon dioxide molecules, demographic changes on financial development in sub-Saharan Africa for the period of 2000-2021, using the dynamic GMM estimation technique. Hence, both difference and system GMM was estimated, but following the results of PMG and FE, system GMM is the most appropriate for the analysis. Thus, in view of the broad and specific objectives, the following hypothesis were tested; (a) carbon dioxide molecules have no significant impact on financial development;(b) population growth has no significant impact on financial development; (c) changes in financial deepening and carbon dioxide omissions have no significant impact on financial development; (d) changes in financial deepening and greenhouse gas emissions have no significant impact on financial development. In addition, we investigate environmental Kuznets (EKC) hypothesis.

The findings thus show that: (a) carbon dioxide molecules emissions have a negative and significant relationship with financial development; (b) population growth has a significant positive relationship with financial development; (c) changes in financial deepening and carbon dioxide omissions have significant negative impact on financial development; (d) changes in financial deepening and greenhouse gas emissions have significant negative impact on financial development. In addition, we found that the postulates of environmental Kuznets (EKC) hypothesis hold in sub-Saharan Africa, and our evidence is found to be consistent with the inverted-U curve relationship. Therefore, we conclude that carbon dioxide molecules emissions have a negative significant connection with credit to the private sector, implying that as environmental sustainability improves, so does financial development. As such, sustainable environmental practices and financial development may coexist and even complement one another in Sub-Saharan Africa. In addition, we conclude that population growth exhibits significant and positive association with credit to the private sector in Sub-Saharan Africa. This shows that as the population grows, so does credit to the private sector, implying that demographic changes are inextricably tied to financial sector development in Sub-Saharan Africa.

Based on the findings explained above, the following policy recommendations were made. First, we encourage the implementation of incentives or subsidies for programs aimed at lowering CO_2 emissions. With this, financial institutions would be encouraged to lend more money to companies implementing sustainable practices and green initiatives. Creating guidelines for the issuance of green bonds can offer a methodical approach to funding eco-friendly initiatives. Policymakers may encourage the expansion of this industry by establishing guidelines and supporting regulations. Economic resilience can be improved by policies that encourage diversification away from carbon-intensive industries. This diversification may be fueled by financial assistance for industries like eco-tourism, sustainable agriculture, and renewable energy. Second, there are significant policy ramifications from the direct relationship between SSA's population growth and private sector credit. Promoting financial inclusion, maintaining financial stability, fostering infrastructural growth, advancing social welfare, and guaranteeing environmental sustainability should be the main priorities for policymakers. By putting these policies into place, SSA nations may take advantage of their growing populations to propel sustainable economic growth and raise the standard of living for their citizens as a whole. Third, the existence of negative significant association between the interaction term (M2/GDP × CO_2) and credit to the private sector; in Sub-Saharan Africa (SSA), indicates that credit to the private sector rises as CO_2 emissions decline. This association suggests that financial development may benefit from efforts to cut emissions. As a result, policymakers have to concentrate on boosting green financing, encouraging carbon pricing, encouraging green investments, and guaranteeing financial stability.

Fourth, credit to the private sector increases proportionately with decreasing GHG emissions in Sub-Saharan Africa (SSA), according to the negative significant connection found between the interaction term (M2/GDP × GHG) and credit to the private sector. The significant and negative association shown between GHG emissions and private sector lending highlights how essential it is to have policies in place that support environmental sustainability while simultaneously preserving financial stability. On the basis of this, we recommend hastening the shift to a low-carbon economy by encouraging green investments. It is also important for policymakers to improve environmental laws, expand access to green funding, and implement carbon pricing schemes. These actions lessen the risks posed by climate change while also creating opportunities for fair and sustainable prosperity in Sub-Saharan Africa.

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