

**CLIMATE CHANGE IN THE SUB-SAHARAN
REGION: IMPACT, TRANSMISSION CHANNELS
AND THE MITIGATION EFFECT FROM
FINANCIAL MARKET DEVELOPMENT ON
CARBON EMISSION**

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by

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LIST OF ABBREVIATIONS

A	Affluence
ADB	African Development Bank
ARDL	Autoregressive Distributed Lag
BRICS	Brazil, Russia, India, China, and South Africa
CCKP	Climate Change Knowledge Portal
CI	Capital Investment
CIR	Capital Intensity Ratio
CO ₂	Carbon Dioxide
CRU	Climate Research Unit
DOLS	Dynamic Ordinary Least Squares
EC	Energy Consumption
FD	Financial Development
GDP	Gross Domestic Product
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
K	Capital
LP	Labor Productivity
LS	Labor Supply
MENA	Middle East and Nor Africa
NA-AMA	National Accounts-Analysis of Main Aggregates
PG	Population Growth
RF	Rainfall
SGMM	System Generalized Method of Moments
TMP	Temperature
UNFCCC	Nations Framework Convention on Climate Change

UNWTO United Nations World Tourism Organization
WDI World Development Indicators

LIST OF APPENDICES

Appendix A Panel data from sub-Saharan Region

**PERUBAHAN IKLIM DI RANTAU SUB-SAHARA: IMPAK, SALURAN
PENYALURAN DAN KESAN MITIGASI DARIPADA PEMBANGUNAN
PASARAN KEWANGAN TERHADAP PENGELUARAN KARBON**

ABSTRAK

Perubahan iklim merupakan cabaran global yang memberi kesan berbeza kepada negara-negara berdasarkan konteks geografi dan ekonomi mereka. Negara-negara Afrika sangat terdedah kerana lokasi dan pergantungan mereka kepada sektor yang sensitif terhadap iklim. Wilayah sub-Sahara menghadapi risiko ekonomi yang besar akibat perubahan iklim, yang menjejaskan produktiviti, pelaburan, dan bekalan buruh. Kajian-kajian sedia ada sering mengabaikan kerumitan kesan ini dan saluran transmisinya, dengan kekurangan analisis yang mendalam mengenai hubungan tidak linear. Kajian ini bertujuan untuk menilai kesan perubahan iklim terhadap pertumbuhan ekonomi di Afrika sub-Sahara, dengan memberi fokus kepada kesan tidak linear suhu dan hujan. Kajian ini juga meneliti bagaimana pembangunan pasaran kewangan dapat mengurangkan kesan tersebut. Menggunakan data dari tahun 1994 hingga 2018 merangkumi 29 negara, kajian ini menggunakan pembolehubah instrumental dan U-test Lind dan Mehlum untuk mengenal pasti hubungan tidak linear, serta semakan keteguhan untuk memastikan kesahan keputusan. Hasil kajian menunjukkan bahawa suhu yang sederhana menyokong pertumbuhan, manakala suhu panas yang melampau memberi kesan buruk. Hujan mempunyai kesan positif terhadap pertumbuhan, tetapi hujan lebat menunjukkan kesan bercampur. Kajian ini juga mendapati bahawa pembangunan kewangan pada awalnya meningkatkan pelepasan karbon, tetapi mengurangkannya pada tahap pembangunan yang lebih maju. Hubungan tidak linear antara suhu dan pelaburan turut disahkan. Kajian ini

menekankan keperluan pelaburan yang disasarkan dalam infrastruktur tahan iklim dan promosi kewangan hijau untuk mengurangkan pelepasan karbon. Penggubal dasar harus memberi fokus kepada strategi adaptif bagi mengurangkan kesan buruk perubahan iklim sambil memupuk pertumbuhan ekonomi jangka panjang di rantau ini.

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ABSTRACT

Climate change poses a global challenge, impacting countries differently based on their geographical and economic contexts. African nations are particularly vulnerable due to their location and reliance on climate-sensitive sectors. The sub-Saharan region faces significant economic risks from climate variability, affecting productivity, investment, and labor supply. Existing studies often overlook the complexity of these impacts and their transmission channels, lacking robust analyses of nonlinear relationships. This study aims to assess the impact of climate change on economic growth in sub-Saharan Africa, focusing on the nonlinear effects of temperature and rainfall. It also examines how financial market development can mitigate these impacts. Using data from 1994 to 2018 across 29 countries, the study employs instrumental variables and the Lind and Mehlum U-test to identify nonlinear relationships, alongside robustness checks to ensure result validity. Results indicate that moderate temperatures support growth, while extreme heat is detrimental. Rainfall positively influences growth, though heavy rainfall shows mixed effects. The study finds that financial development initially increases carbon emissions but reduces them at advanced levels. A nonlinear relationship between temperature and investment is confirmed. The study underscores the need for targeted investments in climate-resilient infrastructure and the promotion of green finance to reduce carbon emissions. Policymakers should focus on adaptive strategies to mitigate the adverse effects of climate change while fostering long-term economic growth in the region.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Climate change denotes the long-term shift in temperature and weather patterns. According to the United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to a change in the global climate that results from human activities altering the composition of the global atmosphere, observed over comparable time periods. In a similar vein, the Intergovernmental Panel on Climate Change (IPCC) characterizes it as a lasting alteration in the climate system, usually spanning decades. This climate system encompasses the atmosphere, geosphere, hydrosphere, and biosphere. It's important to distinguish climate change from weather variation, as the former is a prolonged process, whereas the latter refers to short-term changes that occur daily or annually.

Economic growth, per the definition of the World Bank, is the change in the volume of output, income, and expenditure of residents of a country in a given period. Economic growth is measured by a nation's Gross Domestic Product (GDP). In 2008, the system of national accounts provided three methods for calculating GDP: production, expenditure, and the income approach. The production approach measures the value-added of the gross domestic output from various economic sectors.

In recent decades, scholarly work in economics has advanced significantly in fields concerning environmental, climatic, and natural resource economics. Climate economics examines the nexus between climatic factors, output, factors of production, and the availability of natural resources like water (Arent *et al.*, 2014). Indeed, Climate issues have gained significant consideration in macroeconomic studies. William

Nordhaus, who is among the pioneers of the macroeconomic costs of climate change, has emphasized the need for a serious response to the impacts of climate change (Barrage, 2019). Others, like Joseph Stiglitz and Paul Krugman, have similarly underlined economic issues of climate change. Ever since then, the economic consequences of climate change have become integral to policy design and the macroeconomic models that forecast economic activities (Batten *et al.*, 2020).

Moreover, records have shown that policymakers give considerable attention to the influence of climate change since it is viewed as an externality, whereas the fundamental characteristic of that externality relates to greenhouse gas (GHG). Humans engaging in economic activities discharge multiple chemicals that cause the concentration of GHG and carbon emissions that threaten people's livelihood and ability to perform daily activities (UNFCCC, 2020; IPCC, 2018; Yazdanpanah & Zobydi, 2017; Eboli *et al.*, 2010).

Many empirical studies have indicated that carbon emission and climate change are associated, and their combined effects shift the ecosystem's structure, service, and functionality (Yonglong *et al.*, 2018). Moreover, they bring alarming ecological risks, reduce biomass, change food web dynamics, and diminish economic activities (Brown *et al.*, 2015; Jing *et al.*, 2015; Backhaus *et al.*, 2012; van Dijk *et al.*, 2012). A considerable portion of GDP, welfare, and consumption loss is attributed to carbon-induced climate change (Nam *et al.*, 2010; Hanna & Oliva, 2015; Wan *et al.*, 2005; Graff Zivin & Neidell, 2012).

The relevant studies show that low-carbon policies might mitigate the negative impact of climate change on economic activities in highly polluted areas and even places where carbon emissions are already low. Furthermore, carbon emission

mitigation requires the establishment of policies and financial development (Zhang *et al.*, 2017; Jiang *et al.*, 2013). Theoretically, financial advancement can lessen the disastrous effect of greenhouse gas emissions by financing environmentally clean technology and energy-efficient equipment (Charfeddine & Kathia, 2019). Furthermore, economic growth leads to improved environmental conditions as it stimulates research and development and draws in international investments (Frankel & Romer, 1999).

Conversely, the progression of financial systems could have detrimental effects by increasing household consumption and the demand for goods that consume more energy and emit carbon. The advancement of financial systems also improves the availability of financing options, as many firms are tempted to expand their industrial bases and invest in machines that increase GHG concentration and lead to climate variation (Sheraz *et al.*, 2021; Safi *et al.*, 2021).

1.1.1 The Effect of Climate Change on Economic Growth

Climate change is an unpredictable event that causes a considerable change in economic activities. Economic disturbances can happen, whether on the side of demand or supply. Disruptions to demand influence areas like consumer spending, government expenditures, business investments, and global trade. Meanwhile, supply-side shocks impact the elements of production, including labor, capital accumulation, technology, and infrastructure. Natural disasters, droughts, and rising temperatures trigger demand and supply shocks.

Modern economics emphasizes that high temperature correlates to the GDP decline and significantly influences a country's economic performance. The rise in temperature by 1 °C causes the global GDP to decline by about 1.3 percent (Dell *et al.*,

2012). Moreover, temperature variations cause about 23 percent of the income difference across countries (Burke *et al.*, 2015). The global temperature exceeds historical averages and is heading to historic heights, as 13 of the 15 hottest years occurred in this century (Mann *et al.*, 2016). Low-income countries are prone to severe consequences of temperature variation.

Climate change imposes a particular challenge on African countries due to the nature of the geographical location, low income, and dependence on climate-sensitive sectors. The economy in Africa is mainly vulnerable to climate dynamics. Major sectors pivotal to Africa's economy, including agriculture, energy, and water resources, are heavily reliant on climatic conditions (Abidoye & Odusola, 2015). Exports of agricultural products and oil are a significant source of revenue in Africa, where volatile commodity prices, climate change, and significant barriers to export growth. (Devereux & Maxwell, 2001).

Extreme heat in sub-Saharan countries reduces economic growth as the gap between developed and sub-Saharan countries would be small if the temperature was normal (Barrios *et al.*, 2008). From 1970–2010, many African countries saw a significant rise in the temperature, ranging from 1–3 °C, given that the continent has the smallest contribution to global carbon emissions (Abidoyea & Odusola, 2015). Most countries in sub-Saharan Africa are located in low latitudes, and further warming threatens the continent by exacerbating climate change damage (Mendelsohn, 2008).

Figure 1.1 shows temperature variations across sub-Saharan African countries. The vertical axis measures temperature values, while the horizontal axis lists the countries. The bars indicate relative temperatures in each region. Chad and Sudan have the highest temperature levels, suggesting these countries experience significant heat

stress. Tanzania and Zambia also display elevated temperatures. In contrast, countries like Liberia, Gabon, and Lesotho show lower temperature levels, indicating milder conditions.

These differences have clear implications. Higher temperatures, like those in Chad and Sudan, can hinder agriculture and reduce water availability, impacting economic activities. Regions with lower temperatures may experience different climate challenges, such as changes in rainfall patterns. Each country faces distinct risks, requiring tailored climate adaptation measures to address their specific temperature profiles effectively.

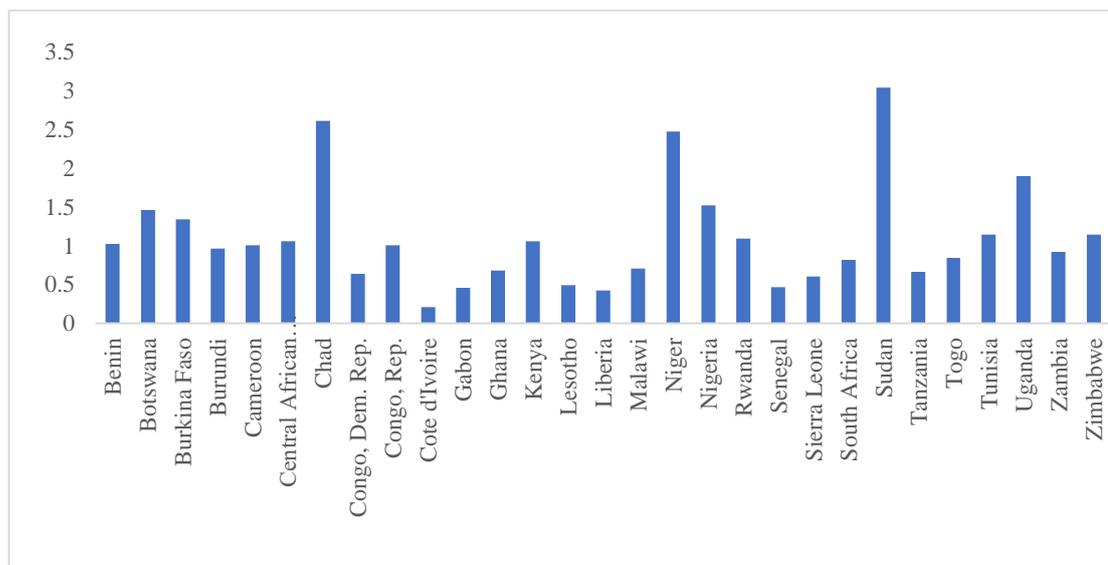


Figure 1.1 Changes in Temperature in Some Sub-Saharan Countries (1961–2009)

Source: Climate Research Unit (CRU)

Rainfall patterns in sub-Saharan Africa are characterized by significant spatial and temporal variability. This region experiences shifts in rainfall across different areas and time periods, influenced by factors such as sea surface temperature changes in the Atlantic and Pacific Oceans. For example, the Sahel region faced severe droughts during the 1970s and 1980s, followed by a partial recovery of rainfall levels

in the 1990s, partly linked to changes in Atlantic Sea surface temperatures (Conway *et al.*, 2009). East Africa, in contrast, has seen periods of relative stability in rainfall, interrupted by occasional years of intense precipitation.

Southern Africa experiences high interannual variability, with rainfall patterns heavily influenced by phenomena like the El Niño-Southern Oscillation (ENSO), leading to cycles of dry and wet years (Monerie *et al.*, 2023). Meanwhile, Central Africa shows less pronounced decadal shifts, with some similarities to the Sahel's patterns in adjacent areas (Conway *et al.*, 2009). These variations create challenges for predicting long-term climate impacts and planning for water resource management and agricultural activities across sub-Saharan Africa.

The temporal availability and spatial productivity of vital economic outputs like agriculture depend on the climate system across various regions globally (Bantin *et al.*, 2017). Variability climate has emerged as the primary cause of numerous economic challenges in the 21st century. These challenges are characterized by a decline in agricultural yield, diminished availability of industrial raw materials, and a consequent reduction in the demand for various services (Tol, 2018; Kahn *et al.*, 2019). The output of agriculture in Africa is heavily reliant on climate dynamics, as the most important economic activities in this field are influenced by weather patterns. Agriculture affects other economic outputs in Africa and satisfies the caloric demands of the population (Mu *et al.*, 2017). With approximately 52 percent of Africa's population directly dependent on agriculture, the sector contributes 17 percent to the continent's GDP, underscoring its critical role in livelihoods and economic stability (World Bank, 2020).

Water sources, soil fertility, temperature, and the general conditions of the weather determine agricultural productivity. Drought is one of the most severe hazards to the African agricultural output. Around 5 to 8 percent of the dry and semi-dry lands are expected to surge in 2100. East, South, and West African countries will experience a loss of agricultural land (IPCC, 2007). In the southern regions of Africa, there has been a marked reduction in maize production, and similarly, wheat production has declined in North Africa (Warren *et al.*, 2006). It is anticipated that the overall balance of cereal production in the sub-Saharan area will be negative. The region might face a loss of approximately 40 percent in its agricultural resources due to changes in the climate. (Fischer *et al.*, 2002).

Climate variability significantly affects the industrial output, with rising temperatures impeding the expansion of industrial production in developing nations. A rise of temperature by about 1°C is associated with a 2.04% reduction in industrial output in low-income countries (Dell *et al.*, 2012). The affected industries are the downstream processors of the agricultural output (Jones & Olken, 2010). Industrial output in Africa is primarily linked to agricultural performance. When a shock hits the agricultural sector, the manufacturing sector suffers from a shortage of input and a decline in demand. Nonagricultural industries like oil and gas, mining, and construction have experienced a substantial decrease in output during the hot seasons. (Hsiang, 2010).

Climate change influences various services in Africa, especially tourism and tourism-linked industries. Wildlife is a tourist attraction in Africa, and the negative impact on the ecosystem tarnishes the attractiveness of tourist sites. Africa has received about 5 percent of the world's inbound tourism since 2008, and this

percentage is predicted to increase. The growth of tourism in Africa is being impeded by escalating temperatures, floods, and droughts (UNWTO, 2009).

This subsection concludes by presenting the average growth rate in sub-Saharan countries, as illustrated in Figure 1.2, which shows the overall growth rate.

The figure shows that sub-Saharan countries reached their highest growth in 1970 when most African countries gained sovereignty and depended on international support. The growth rate in the 1970s was nearly 10 percent, the highest the region ever realized, but the economy declined in 1972 due to the global oil crises. The sub-Saharan countries experienced the lowest growth rate in 1984, at -5.5 percent. The global debt crises, droughts, and the absence of rains that lasted from 1980–1983 led to the decline of the growth. The economy started to grow from 1984–1990.

In the early 1990s, numerous countries in sub-Saharan Africa fell into civil unrest, experienced state failures, and saw a downturn in economic growth. During the 2000s, countries in sub-Saharan Africa experienced significant and steady economic growth, which was then disrupted by the impact of the coronavirus pandemic. The figure shows that the region's growth rate has fluctuated over the last decades. A small change in climate or weather conditions leads to a drastic change in Africa's economy and poverty.

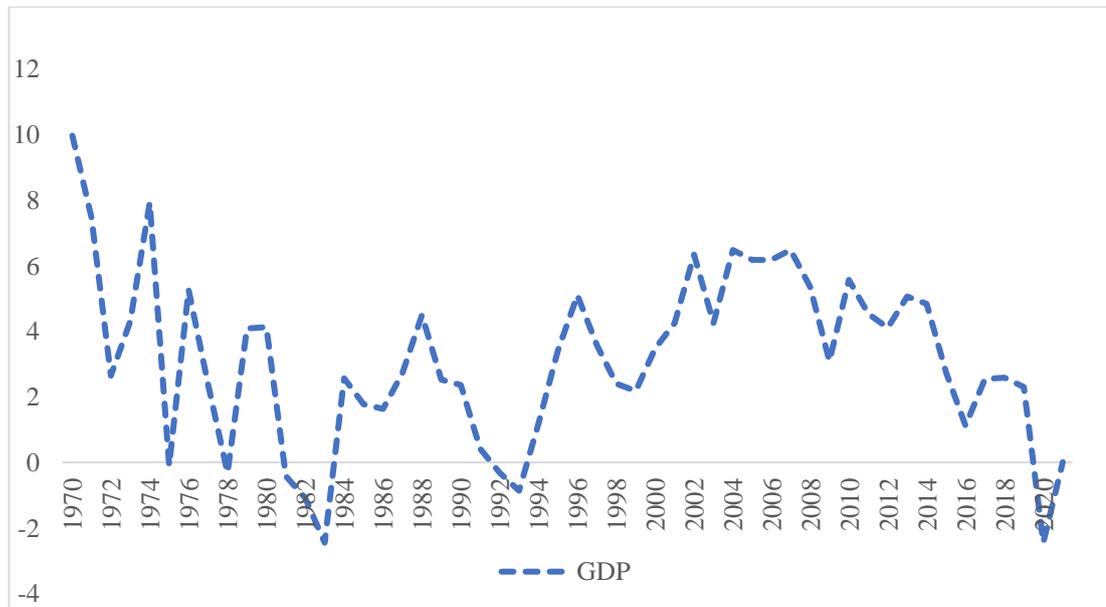


Figure 1.2 Average Gross Domestic Product Growth Rate (GDP) in Sub-Saharan Countries.

Source: WDI (2020)

1.1.2 Transmission Channels of Climate Change

The impact of the climate change is conveyed through a multitude of pathways. These channels can be conceptualized in the form of output, multiple factors of the inputs, and technological efficiency (Batten *et al.*, 2020). Thus far, the critical transmission channels identified by the literature are labor productivity, labor supply, and capital investment. The workplace temperature impacts labor productivity by influencing the mental and physical performance of the laborers. It has been argued that outdoor labor activities decline in high-temperature places and improve when the temperature decreases (Zivin & Neidell, 2014). A meta-analysis and laboratory experiment in a sample of the 28 Caribbean-basin countries showed that task efficiency declines by about 1–2 percent as the temperature rises above 25 °C. (Hsiang, 2010). Additionally, a sample of 147 workers studied in India indicated that output per worker

drops by approximately 3 percent with each 1 °C increase in temperature (Somanathan *et al.*, 2021).

Over the last two decades, the labor productivity growth of the sub-Saharan region was a little above one percentage point per year, and the labor productivity growth in the nonagricultural sector was near zero. The share of the manufacturing industry of labor productivity was 0.25 percent (McMillan & Zeufack, 2022). Labor is 4.5 times less productive in the agriculture sector in low-income countries, but in Africa, labor is six times less productive in the agriculture sector compared to other economic sectors (Gollin *et al.*, 2014). The low labor productivity in the sub-Saharan region is attributed to the failure of the agriculture sector to upgrade their added value and the inability of manufacturing firms to create productive jobs (Teal, 2016). In addition, climate change adversely affects work conditions and further diminishes African labor productivity (McGuirk & Nunn, 2020).

The availability and the ability of labor are primarily affected by climatic variation. Climate change impacts the labor supply by influencing health and birth and mortality rates. Infant mortality rises during the hot seasons, and many children die from climate-linked diseases (Acevedo *et al.*, 2020). Heat and rising temperatures affect laborers' health, mortality, and mobility and influence education acquisition and mental strength (Watts *et al.*, 2015; Park, 2017). The frequency of the biophysical risks to human beings and the emergence of new diseases are also climate-induced incidents. In Africa, unpredictable rainfall patterns contribute to the widespread occurrence of illnesses such as diarrhea and malaria. Particularly, diarrhea has been a significant factor in the continent's health crises, resulting in millions falling ill annually (WHO, 2005).

Population growth is a major factor influencing labor supply in various regions globally. The sub-Saharan area, in particular, is experiencing a swift increase in population. A significant segment of this region's population is youthful, and it is anticipated that the population will continue to grow throughout this century (Arthi *et al.*, 2018). Developing countries have experienced a decline in population growth, and the sub-Saharan region was marked as the only region with a significant rise in fertility (Shapiro & Gebreselassie, 2007). Although several countries in the sub-Saharan region have experienced declining fertility rates, in most countries, fertility and births are increasing (Temitope, 2013).

The population growth rate was 2.5% in sub-Saharan Africa, 1.2 in East Asia, and 0.1 percent in Europe. The sub-Saharan population growth is driven by the high fertility rate, which was 5.2 percent; by comparison, the fertility rate was 2.5 percent in Latin America and 1.6 percent in Europe (World Bank, 2022). Although population growth in Africa was significant, infant mortality, climate-borne diseases, illiteracy, and a lack of proper education harmed the supply of effective labor in Africa (Abidoye & Odusola, 2015). In Africa, the growth of effective labor tends to plateau as it predominantly relies on the agricultural commodity system. The labor supply responds to changes in commodity prices rather than the total number of workers. Higher commodity prices attract more workers to those sectors due to better earnings, while lower prices can reduce labor supply in those areas (Van, 2020).

Climate change impacts capital formation by accelerating capital depreciation due to increased heat and environmental stress. This reduces the productivity of machinery and equipment used in production, leading to lower investment returns. Climate shocks diminish the availability of investment resources, particularly in economies with imperfect capital markets, where access to financing is already limited

(Fankhauser & Tol, 2005; Hallegatte *et al.*, 2016). The heightened risks associated with climate impacts further discourage investment in vulnerable industries, as the uncertainty drives investors away from sectors most exposed to climate variability. Households in these regions often resort to liquidating productive assets, as dwindling savings and limited access to credit create financial strain.

As temperatures rise beyond certain thresholds, a significant share of investment shifts toward adaptation measures rather than productive capital, negatively affecting overall output growth (Pindyck, 2013; Pindyck, 2011). Sufficient investment is critical to address climate shocks and maintain economic stability. However, in Africa, domestic investment remains limited, counteracting efforts to mitigate the adverse effects of climate change (Ali, 2012). Historically, the investment share of GDP has declined, from 25 percent in the 1970s to 19 percent in the 2000s. Investment growth has been further constrained by high interest rates, driven by public debt levels that have remained around 59 percent of GDP since 2017 (Fagbemi & Olatunde, 2019; Anyanwu, 2006).

To sum up, climate change affects labor productivity by reducing work hours. The rise in temperature and humidity leaves laborers unable to perform their duties during the hot hours and dissipate from the workplace. Climate change accelerates the machines' depreciation by increasing the equipment's heat, while climate-related incidents make investment in the affected sectors riskier and less attractive. The rise in temperature is linked to health threats, and rainfall raises climate-induced diseases, increasing the labor force's mortality and mobility.

1.1.3 The Role of Financial Development in Carbon Emission

The expansion of the financial system is closely linked with economic development as well as environmental sustainability. There is an argument that in some low-income countries, the magnitude of the financial sector and economic growth are key factors influencing carbon emissions (Zhang, 2011). In this context, African countries have striven to strengthen the institutional framework and promote macroeconomic stability by targeting financial development (African Development Bank [ADB], 2017).

Financial deregulation in Africa was initiated in the late 1980s, and many African countries adopted a new policy to reform and liberalize the financial system. The new policies granted autonomy to the central bank to apply monetary policy as a market-based policy instrument. Initial reforms in Africa's financial framework promoted a broader range of financial services, yet issues such as instability and limited liquidity obstructed the advancement of capital markets and interbank transactions (Reinhart & Tokatlidis, 2003).

The financial sector in Africa has seen significant improvement over the last few decades. A number of reforms, including the removal of credit ceilings, the liberalization of interest rates, and the privatization of state-owned banks, have driven the advancement and expansion of the financial industry. In Africa, particularly in the bank-based segment, there has been notable progress. Private sector credit relative to GDP increased from 10 percent in 1995 to an impressive 21 percent in 2014, and it grew by over 38 percent by 2020 (Mlachila *et al.*, 2016; World Bank, 2020). The market-based financial sector also improved substantially as the initial public offering

and the transactions in the equity markets increased during the last five years (Wudu *et al.*, 2018).

Current empirical research offers differing perspectives on the influence of financial progress on the sustainability of the environment, yielding varied outcomes and inconsistent conclusions. Certain studies contend that financial development can lower carbon discharges by drawing in eco-friendly investments, encouraging research and innovation, and averting environmental damage (Gok, 2020). Similarly, financial development facilitates the availability of environmentally friendly technology, helping firms develop a production process that is clean and efficient and helping governments invest in green technology (Paramati *et al.*, 2017; Yuxiang & Chen, 2010).

Others maintain that financial development raises domestic demand, increases energy consumption, and causes carbon emissions. Households' access to finance leads to increased purchases of various energy-consuming goods and machinery while also encouraging industrialization among firms. Consequently, the number and size of manufacturing companies expand, resulting in elevated emissions of greenhouse gases (Sadorsky, 2010; Xing *et al.*, 2017; Aye & Edoja, 2017).

The financial industry in the sub-Saharan has gained from recent advancements in the institutionalization of the financial system. Prior to the 2007–2008 financial crises, the sub-Saharan region experienced sizable improvements in liquid liabilities, credits, and deposits of the private sector. Many counties in the region deepened their financial systems and expanded the credit-to-GDP ratios from 1995 to 2014 (Boufateh & Saadaoui, 2020). Additionally, the banking sector in Africa has become more profound and accessible due to information and communication technology (Mlachila

et al., 2016). Some countries have also significantly improved their capital market liquidity, diversified the debt market, and increased liquidity and marketable securities (Abdouli, 2016).

Figure 1.3. shows the liquid liability and the financial system deposits in the sub-Saharan region. Liquid liability and financial deposits are high in countries that have undergone financial liberalization and economic reforms in the last decade. Seychelles, Cape Verde, Namibia, and South Africa have experienced improvements in capitalization. Some other countries, like Sudan, Uganda, and Nigeria, are constrained by limited access to debt funding, foreign exchange risk, and currency depreciations. Nonetheless, more efforts are needed to develop the financial market.

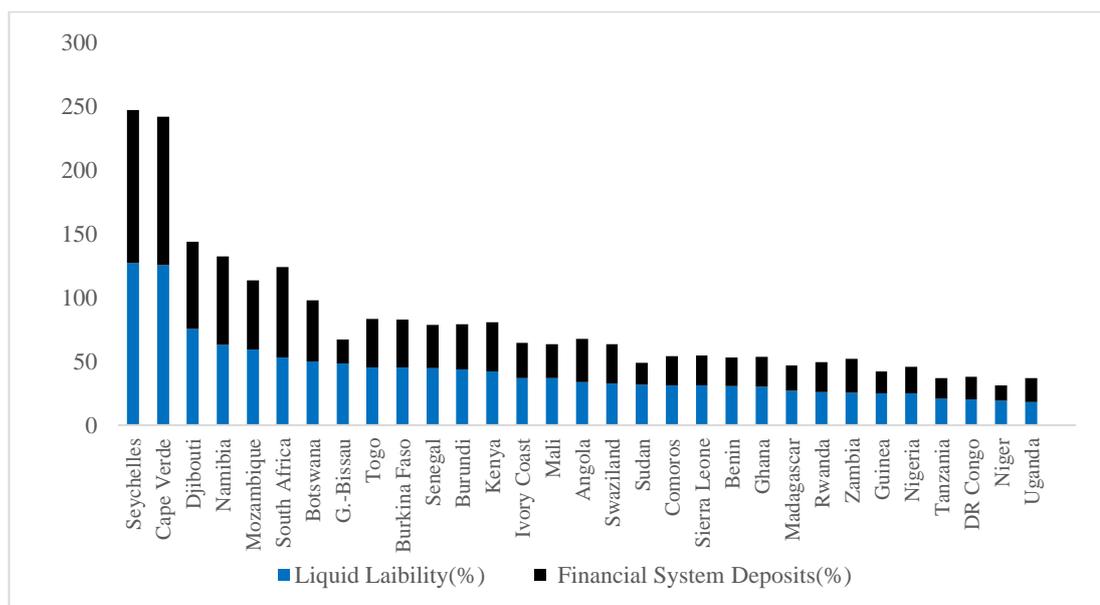


Figure 1.3 The Liquid Liability and the Financial Deposits in Sub-Saharan African Countries

Source: GlobalEconomy.Com

The financial markets in the sub-Saharan region are growing considerably, but they are still challenged by the lack of market depth, thin trading, and a low turnover ratio, which has caused African financial markets to be labeled inefficient. Financial

markets are still liquid, with a turnover ratio of less than one (Raga & Tyson, 2021). The liquidity challenges in African financial markets are linked to minimal secondary market trading, a small number of registered companies, and long settlement periods (Mutize *et al.*, 2020).

Table 1.1 shows the financial-market development in the equity and bond markets across 14 countries in the sub-Saharan region in 2018. Market capitalization as a percentage of GDP shows market size relative to the economy. South Africa leads at 358%. Botswana follows with 269%, and Mauritius stands at 80%. Kenya and Nigeria have smaller markets, at 28% and 13%.

Equities turnover reflects trading frequency. South Africa's 41% indicates active trading. Kenya's 8% suggests lower liquidity. Higher turnover means more frequent trading, while lower turnover suggests a less active market. Bond market turnover measures trading in the bond sector. South Africa shows a high rate of 970%, indicating strong liquidity. Zambia follows with 15%. Most others show limited activity. Lower turnover can make buying or selling bonds more difficult.

Total bonds outstanding represent the size of each country's bond market. South Africa stands out with \$195 billion in bonds. Nigeria's bond market totals \$16 billion. Other countries have smaller markets, indicating fewer options for bond investment. South Africa emerges as the most developed market for stocks and bonds. It has a large market size and high trading activity. Most others have smaller, less liquid markets. They have room for growth and development.

Table 1.1 Indicators of the African Financial Market

Country	Capital Market capitalization, % of GDP	The total turnover of equities, percentage of Market capitalization	Total turnover in a bond market, percentage of Bonds outstanding	Total sovereign and corporate bonds outstanding, listed on exchanges, \$Billion
South Africa	358	41	970	195
Kenya	28	8	48	9
Tanzania	18	2	4	2
Mozambique	9	0	4	0
Nigeria	13	4	0	16
Ivory Coast	35	4	4	5
Mauritius	80	4	0	6
Seychelles	10	2	-	0
Zambia	32	0	15	2
Botswana	269	1	5	1
Uganda	25	1	-	2
Ghana	32	1	7	12
Namibia	24	1	0	12
Rwanda	40	1	2	0

Source: African Securities Exchanges Association, OMFIF Analysis (2018)

Financial markets can support carbon reduction through mechanisms such as green bonds, which fund climate-friendly projects, attracting investors focused on sustainability (Flammer, 2021). These bonds create a channel for reducing carbon footprints by financing renewable energy and other sustainable projects. Additionally, well-developed financial markets can enable carbon trading systems, allowing companies to offset emissions and achieve broader reductions across industries (Huang *et al.*, 2022).

Carbon emissions in Sub-Saharan Africa are influenced by economic growth and industrialization. Despite contributing only about 3.8% to global greenhouse gas emissions rapid urbanization and a heavy reliance on fossil fuels have intensified the issue (Bedair *et al.*, 2023). Weak governance and limited adoption of renewable energy hinder effective mitigation efforts. Transitioning to renewable energy requires robust policies and significant investments (Djellouli *et al.*, 2023). Sub-Saharan

Africa's carbon emissions are significant due to rapid urbanization and reliance on fossil fuels, which drive environmental degradation and contribute to climate change. Although the region accounts for a small fraction of global emissions, its emissions growth rate is among the highest due to economic and industrial expansion (Ayimadu *et al.*, 2024).

Figure 1.4 shows carbon emissions per capita in Africa from 1990 to 2023. It highlights the low and stable emissions levels, ranging between 0.4 and 0.8 metric tons per person, compared to global averages of 4.7 metric tons. Minor fluctuations occur, with a noticeable drop around 2020, likely due to reduced industrial activity during the COVID-19 pandemic. The data reflects Africa's minimal contribution to global emissions while emphasizing its vulnerability to future increases with economic growth and industrialization.

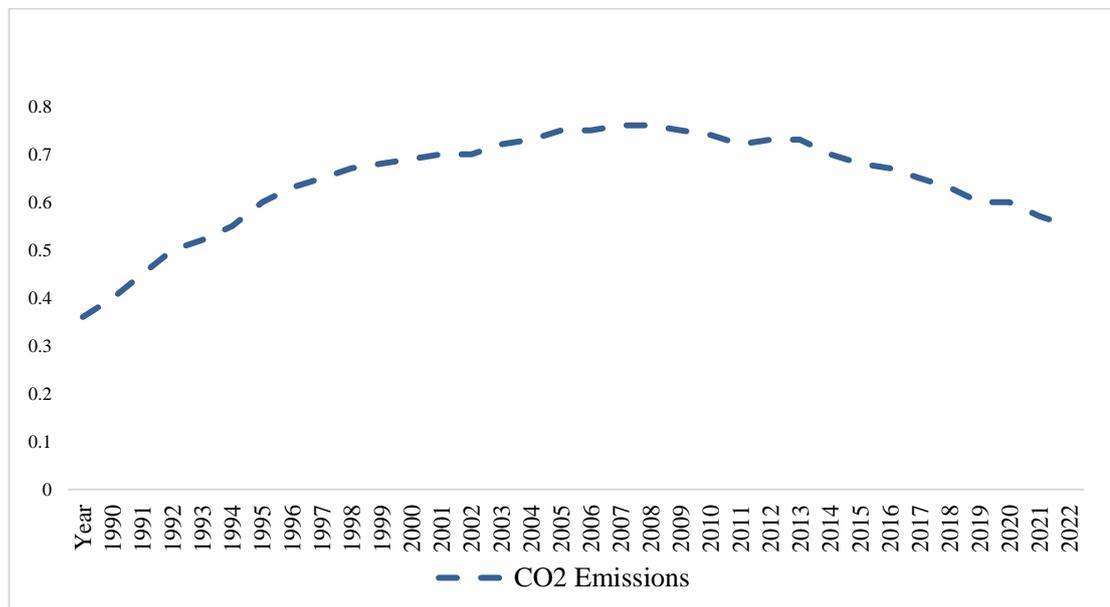


Figure 1.4 Carbon Emission Per Capita in Africa (1990–2023)

Source: Our World in Data

1.2 Problem Statement

Climate change affects countries differently, depending on geography and development, with sub-Saharan Africa particularly vulnerable due to its location and dependence on climate-sensitive sectors. Research, such as that by Jamilu *et al.* (2023), Esra and Omer (2020), and Lanzafame (2012), highlights the region's challenges but often assumes a linear relationship between climate and growth, missing critical complexities.

This study reexamines climate change's impact on economic growth in sub-Saharan Africa because prior research, like Barrios *et al.* (2010), Abidoye and Odusola (2015), often overlooks potential nonlinearities. Evidence from other regions suggests that moderate climate shifts can initially boost growth but become damaging at higher levels. Yet, this nonlinear pattern remains underexplored in sub-Saharan Africa, creating a gap in understanding how temperature and rainfall changes might alternately help or harm economic activities. By investigating these nonlinearities, this research focuses on how shifts in temperature and rainfall affect economic outcomes, emphasizing the importance of understanding threshold effects. This approach is vital for designing policies that support sustainable growth in the region's unique climate conditions.

Climate change has a profound impact on the economy, influencing key elements over the long term. Research by Kalkuhl and Wenz (2020), Carleton and Hsiang (2016), and Burke *et al.* (2015) shows that temperature and rainfall fluctuations affect productivity growth. Extreme events like droughts and floods further disrupt labor productivity, capital investment, and labor supply (Berlemann & Wenzel, 2016; Noy, 2016).

However, prior studies often assume a linear relationship between climate change and these impacts, missing the complexity. They overlook how moderate climate shifts might initially support growth, while extreme conditions harm it (Burke *et al.*, 2016; Stern, 2013). This underestimation of long-term costs shows a need for reevaluation. This thesis uses a nonlinear approach to explore these dynamics, revealing thresholds where climate effects change from beneficial to harmful. It focuses on the sub-Saharan region to provide a clearer understanding of how climate fluctuations impact key economic variables. This approach aims to fill the gaps in previous research, offering more precise insights into the economic consequences of climate change.

Understanding the relationship between economic growth and carbon emissions is essential for sustainable development. Financial development significantly influences this connection, yet the literature remains divided on how these elements interact. Some studies, such as Shahzad *et al.* (2017) and Paramati *et al.* (2017), find that financial development increases carbon emissions through industrial expansion. Others, like Ren *et al.* (2023) and Odhiambo (2020), suggest that advanced financial systems support green technologies, reducing emissions. Meanwhile, Abbasi and Riaz (2016) and Salahuddin *et al.* (2015) identify no significant connection between economic growth and emissions. These conflicting findings highlight a gap in understanding the complex interactions between financial development and carbon emissions.

Most existing studies assume a linear relationship between financial development and emissions, missing critical variations that occur over time. A nonlinear perspective is necessary because financial development's impact changes—starting with increased emissions from economic activities but potentially decreasing

as financial systems mature and support cleaner technologies. This study adopts a nonlinear approach to better understand these shifts. This study incorporates population growth to provide a fuller picture of how demographic changes contribute to environmental pressures. Population growth plays a critical role in the analysis as it directly influences energy demand and, consequently, emissions. As the population increases, so does the need for energy across various sectors, from residential and commercial to industrial and transportation. This rising demand typically leads to higher energy production and consumption, which, without sustainable practices, can result in increased emissions (Alam *et al.*, 2012).

1.3 Research Questions

This study seeks to answer the following research questions:

- i) How does climate change affect real GDP growth in sub-Saharan Africa in a linear and nonlinear framework?
- ii) What is the effect of climate change on transmission channels (i.e., labor productivity, investment, and labor supply) in the sub-Saharan region in a nonlinear framework?
- iii) What is the role of financial development in carbon emission in sub-Saharan region countries in a nonlinear framework?

1.4 Objectives of the Study

This thesis mainly focuses on assessing how climate change impacts economic growth in the sub-Saharan region, exploring the various channels through which these effects are transmitted. Additionally, it investigates how financial development

influences carbon emissions, aiming to discern its potential mitigating effects on climate change.

This study sets out the following specific objectives:

- i) To measure the effect of climate change on the real GDP growth in sub-Saharan Africa in a linear and nonlinear framework.
- ii) To determine the effect of climate change on transmission channels (i.e., labor productivity, investment, and labor supply) in the sub-Saharan region in a nonlinear framework.
- iii) To identify the financial development's role in carbon emission in the sub-Saharan region in a nonlinear framework

1.5 Scope of the Study

This study utilizes panel data from 1990–2018 from 29 sub-Saharan regions. This region denotes the section of the African continent located to the south of the Sahara Desert, including the southern and eastern regions of Africa. Per the United Nations' definition, the sub-Saharan region includes all countries and territories that fully or partially lie to the south of the Sahara in Africa. The sub-Saharan region contains 46 countries.

This study examines sub-Saharan countries due to their economic reliance on climate-sensitive sectors and the fact that they share common characteristics like the inability to handle the effects of climate change. Moreover, most sub-Saharan countries are neighboring countries with climate correspondence and have close economic growth trajectories. Additionally, the impacts of climate change are more

observable in developing nations, as wealthier nations often have greater resources and capabilities to cope with climate change challenges, thereby masking its costs.

1.6 Significance of the Study

This thesis focuses on exploring how climate change might impact the economic progress of the sub-Saharan area. In greater detail, this dissertation offers empirical proof of the influence of climate variability on economic progress in sub-Saharan Africa. It takes into account the nonlinear association between economic growth and climatic indicators, including temperature fluctuations and precipitation levels. Temperature and rainfall are critical factors in assessing how climate change influences ecosystems, economies, and human livelihoods. The rise in temperature is linked to increased heat waves, leading to illness, low factor productivity, and even death. On the other hand, rain and snowfall variations affect water for drinking and irrigation. Policymakers must understand that temperature and precipitation disturb natural processes, especially if these changes occur frequently and quickly.

Equally important, previous studies that examined this domain relied on micro-level analyses, and no attention has been given to the channels that link climate change to economic growth. To my knowledge, this study represents a pioneering effort in the sub-Saharan region, specifically in its investigation of the diverse channels by which climate change affects the environment. Hence, this dissertation endeavors to measure the effect of temperature and rainfall on productivity of the labor, investment, and the availability of labor. Mounting research indicates that climatic conditions dramatically and nonlinearly impact economic activities and the essential productive elements of the economy, such as labor, output, and investment.

Presuming a linear impact of climate on economic growth and its transmission mechanisms leads to inaccurate policy suggestions, which cannot account for the possible nonlinearity influences. This research enhances the existing body of knowledge by exploring the linear as well as the non-linear influence of climate variability on economic progress, including the various transmission channels involved. Additionally, it delves into the non-linear interactions between carbon emission and economic growth, specifically within the context of the sub-Saharan region.

Africa's economic growth has significantly influenced the evolution of its financial system and carbon dioxide emissions. As the continent navigates early development stages, it progresses towards more expansive economic growth. Understanding the role of financial development on carbon discharges is crucial, yet this area remains inadequately studied and has not received extensive attention in current research. Moreover, the lack of financial access raises the climate vulnerability in the sub-Saharan region and increases reliance on traditional practices that pollute the environment. While previous discussions suggest that financial advancement might be negatively associated with carbon discharges, this research adds to existing knowledge by presenting additional information regarding the link between economic growth and carbon discharge, specifically focusing on the sub-Saharan region.

More importantly, the omission of the critical variables constrains empirical papers that examined this issue in the sub-Saharan region. Earlier research has often neglected the role of human activities in carbon emissions and has failed to consider the effects of population growth, particularly in the context of the sub-Saharan region, where the population is rapidly growing. This thesis strives to address this knowledge gap by exploring the connection between financial development and carbon emissions