

CLIMATE ADAPTATION FINANCE AND ECONOMIC GROWTH IN SUB-SAHARA AFRICA

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Abstract

Sub-Saharan Africa remains one of the most climate-vulnerable regions globally, grappling with the dual challenge of environmental instability and underdeveloped economic structures. As nations in the region increasingly turn to climate adaptation finance to build resilience and stimulate economic performance, there is a critical need to empirically assess the effectiveness of these financial interventions. This study investigated the effect of climate adaptation finance on economic growth. Climate adaptation finance is represented by Adaptation Fund (ADF), Environmental Facility Fund (EFF), Renewable Energy Fund (REF), Renewable Agricultural and Forest Fund (RAF), and Green Bond Issues (GBI) while economic growth is represented by Gross Domestic Product (GDP). Using annual a 13-year data, the study applied the Generalized Method of Moments (GMM) estimation technique. Findings from the GMM estimation reveal that RAF was statistically significant on GDP. In contrast, ADF, EFF ($-0.0054, p = 0.873$), GBI ($-0.0078, p = 0.620$), and REF ($1.1722, p = 0.756$) showed statistically insignificant effects on GDP. The study concluded that while climate adaptation finance holds potential for advancing economic development, its effectiveness varies by sector. The study recommended that priority should be given to agriculture and forest-based interventions. Additionally, improving institutional efficiency, fund disbursement mechanisms, and monitoring frameworks will be essential to optimize the developmental outcomes of climate adaptation finance in Sub-Saharan Africa.

Keywords: Climate-Adaptation-Finance, Economic Growth, Sustainable Livelihoods, Sub-Sahara Africa.

1. Introduction

In last decade climate change has emerged as one of the most pressing challenges facing humanity, with disproportionately severe consequences for developing regions, particularly Sub-Saharan Africa (SSA) (World Bank, 2024). While global carbon emissions largely originate from industrialized nations, the brunt of climate-induced adversities, ranging from droughts and floods to food insecurity and ecosystem disruptions, is felt most acutely by low-income countries (Presidential Climate Committee (PCC), 2023). This uneven vulnerability necessitates the mobilization of climate adaptation finance to foster resilience, especially in SSA, where development challenges intertwine with environmental degradation and economic fragility (Gemayel et al., 2025). Yet, the linkages between climate adaptation finance and economic growth in this region remain underexplored, creating a significant gap in

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both policy discourse and academic literature.

Globally, the need for climate finance has become a central tenet of environmental policy since the Paris Agreement of 2015. Adaptation finance, distinct from mitigation, seeks to bolster countries' abilities to cope with current and future climate risks. The United Nations Environment Programme (UNEP) estimates that developing countries will require up to \$340 billion annually for adaptation by 2030 (UNEP, 2023). However, only a fraction of this is currently mobilized, with Africa receiving less than 10% of the total climate finance flows, and even less earmarked specifically for adaptation. This financing gap is further exacerbated by institutional inefficiencies, poor absorptive capacity, and fragmented donor priorities across the African continent (Rishi et al., 2025).

At the continental level, several policy frameworks have attempted to integrate climate adaptation with economic development. The African Union's Climate Change and Resilient Development Strategy (2022–2032) and the African Development Bank's Climate Action Plan are two such instruments aimed at improving coordination, financing, and implementation of adaptation projects. However, implementation has been inconsistent, often undermined by national-level barriers such as weak governance, limited fiscal space, and lack of robust data for climate planning (Okesiji, 2025). In this context, adaptation finance can be a transformative lever, if strategically deployed—to enhance resilience and productivity, thereby catalyzing long-term economic growth.

In Sub-Saharan Africa, made up of 49 countries located south of the Sahara Desert, the issue of climate adaptation finance is particularly urgent, due to the paucity of funds and increasing climate -related problems (Akanni, 2025). The region is simultaneously the least responsible for greenhouse gas emissions and the most exposed to the vagaries of climate variability. Recent studies have shown that more than 60% of SSA's population depends on climate-sensitive sectors such as agriculture, fisheries, and forestry (Akanni et al., 2025). Climatic disruptions, therefore, do not just pose environmental threats, they have direct economic consequences. Prolonged droughts reduce crop yields, flooding destroys infrastructure, and erratic weather patterns disrupt energy supply, ultimately stalling economic growth and aggravating poverty (Chirisa et al., 2025; Byaro & Rwezaula, 2025). These impacts underscore the criticality of financing mechanisms that enhance adaptive capacities and promote sustainable economic trajectories.

From a national or local perspective, individual SSA countries exhibit varying capacities and needs for adaptation. For instance, nations like Kenya and Senegal have pioneered climate-resilient development through green bonds and community-based adaptation programs, while others remain heavily reliant on donor-driven projects with limited domestic financial input (Taera & Lakner, 2025). Importantly, localized adaptation, such as sustainable agriculture, water resource management, and resilient infrastructure, has the dual benefit of protecting livelihoods and spurring economic activity (Benegiamo, 2025). Moreover, adaptation finance when properly aligned with national development priorities, can help build institutional capacity, foster innovation, and attract private sector investment, thereby embedding resilience into the economic fabric.

Climate adaptation finance is commonly proxied through indicators that capture both the scale and nature of financial flows dedicated to resilience-building initiatives. These include total adaptation-specific disbursements from multilateral and bilateral sources, concessional loans, and grants directed towards climate-resilient infrastructure

sustainable agriculture, and disaster risk management (UNEP, 2023; Rishi et al., 2025). Additional proxies encompass the proportion of climate finance allocated to adaptation relative to mitigation, as well as per capita adaptation expenditure (Gemayel et al., 2025).

According to World Bank (2024), gross domestic product (GDP) per capita remains the most widely used indicator of economic growth, reflecting changes in overall economic output adjusted for population size (World Bank, 2024). Other proxies include annual GDP growth rates, sectoral value-added, particularly in climate-sensitive sectors such as agriculture and energy—and labor productivity metrics (Byaro & Rwezaula, 2025; Nyathi et al., 2025). Combining these measures allows for an empirical assessment of how targeted climate adaptation financing correlates with macroeconomic performance and sectoral resilience in Sub-Saharan Africa. Such an approach enables policymakers and researchers to evaluate not only the adequacy of adaptation investments but also their role in fostering sustainable, climate-resilient economic growth (Okesiji, 2025).

Despite these potential benefits, the empirical nexus between adaptation finance and economic growth in SSA is neither clearly established nor adequately analyzed in existing literature. Much of the current research either focuses narrowly on climate impacts or broadly on economic growth, with limited integration of climate adaptation as a growth-enabling strategy. This gap is critical given the increasing frequency of climate shocks and the region's aspirations under the African Continental Free Trade Area (AfCFTA), Agenda 2063, and the Sustainable Development Goals (SDGs), especially SDG 8 (decent work and economic growth) and SDG 13 (climate action) (Nyathi et al., 2025; Byaro et al., 2025).

The central research problem guiding this study is: How does climate adaptation finance affect economic growth in Sub-Saharan Africa? While the intuitive expectation is that adaptation spending reduces vulnerability and enhances productivity, the actual transmission channels, contextual variables, and long-term effects remain underexplored. This study examines whether and how climate adaptation finance fosters growth in SSA, considering structural bottlenecks and policy environments.

The significance of this study cannot be overstated. Climate finance, particularly for adaptation, has often been viewed through a humanitarian or environmental lens, sidelining its economic implications. This research reorients that perspective by positioning adaptation finance as an enabler of inclusive, resilient, and sustainable growth. In doing so, it seeks to inform national policymakers, regional development banks, international donors, and civil society actors on how best to target and structure climate finance interventions.

2. Literature Review

Conceptual Issues

Climate Adaptation Finance in Sub-Saharan Africa

Climate adaptation finance (CAF) refers to the financial resources allocated to help countries cope with the adverse impacts of climate change. In Sub-Saharan Africa (SSA), where climate vulnerability is acute and institutional capacity is uneven, adaptation finance has become both a developmental imperative and a governance challenge. SSA countries contribute minimally to global greenhouse gas emissions but suffer disproportionately from climate-induced shocks such as prolonged droughts, floods, and cyclones, which jeopardize livelihoods, food security and macroeconomic

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stability (Gemayel et al., 2025).

The conceptualization of CAF in the region often reflects a dual function: it is both a means of safeguarding existing development gains and a catalyst for resilient growth. However, access to climate finance remains constrained by high transaction costs, complex eligibility requirements, weak absorptive capacities, and competing global donor interests (Lee et al., 2025). These barriers hinder the effective flow of adaptation finance to the most vulnerable communities, despite global commitments under the Paris Agreement and the Green Climate Fund.

Recent literature has emphasized the need for fit-for-purpose financial mechanisms tailored to SSA's structural and institutional realities. Muriithi et al. (2025) advocate for decentralized adaptation finance that empowers local governments and community-based organizations, arguing that such proximity enhances accountability, contextual relevance, and implementation efficiency. Similarly, Mugisha et al. (2025) highlight the role of land readjustment and urban climate resilience planning as pivotal in channeling adaptation finance into sustainable infrastructure and equitable service delivery.

Moreover, innovation in financing modalities is gaining ground. Instruments such as resilience bonds, green insurance, and blended finance models are emerging as potential vehicles to crowd in private sector investment and reduce donor dependency (Hamzat et al., 2024). These innovations are crucial given the substantial funding gap. According to UNEP (2023), adaptation costs in developing countries could rise to \$300 billion annually by 2030, yet less than 10% of global climate finance is currently allocated to adaptation, with SSA receiving an even smaller share.

A recurring theme in the literature is the disparity between climate vulnerability and financial allocation. Lee et al. (2025), in their global analysis of World Bank climate finance, found that adaptation funding often fails to reach the most climate-vulnerable nations. Instead, middle-income countries with better institutional frameworks tend to receive more support. This calls for a recalibration of funding criteria to prioritize need and impact over creditworthiness and bureaucratic performance.

Additionally, the conceptual debate extends to whether adaptation finance should be considered a form of development aid or as a legal obligation stemming from historical emissions by industrialized nations. Benegiamo (2025) critiques the framing of adaptation finance within a “developmentalist” logic, which often depoliticizes climate justice and undermines local agency. She argues for an emancipatory approach that centers African ecological sovereignty and challenges extractive economic relations.

Despite these theoretical insights, the empirical evidence on the economic impact of adaptation finance remains sparse. However, some studies suggest positive correlations between CAF and improved agricultural productivity, reduced disaster losses, and enhanced social welfare (Adesogan et al., 2025). This justifies the argument that adaptation finance, if efficiently managed, can yield multiplicative development dividends, aligning environmental resilience with inclusive growth.

Instruments of Climate Adaptation Finance

Climate adaptation finance is operationalized through a variety of dedicated funds and instruments designed to enhance resilience to climate change impacts. The Adaptation Fund (ADF), established under the Kyoto Protocol, provides grants to finance concrete adaptation projects in developing countries, emphasizing country-led

proposals that address sector-specific vulnerabilities such as agriculture, water resources, and infrastructure (UNEP, 2023; Lee et al., 2025). The Global Environment Facility (GEF), through its Least Developed Countries Fund and Special Climate Change Fund, channels resources toward adaptation planning, early warning systems, and community-based resilience initiatives, often leveraging co-financing from development partners (Gemayel et al., 2025).

Similarly, the Renewable Energy Fund (REF) is conceptualized as a targeted financing mechanism to scale up renewable energy technologies, thereby reducing climate vulnerability by enhancing energy security and diversifying energy sources (Hamzat et al., 2024). The Renewable Agricultural and Forest Fund (RAFF) focuses on promoting climate-smart agriculture, sustainable forestry, and land restoration programs, activities directly linked to food security and ecosystem resilience (Muriithi et al., 2025).

Green bonds have emerged as an innovative market-based instrument that mobilizes capital for environmentally sustainable projects, including climate adaptation initiatives such as flood defense systems, drought-resistant crops, and resilient transport infrastructure (Mugisha et al., 2025). By attracting private investment alongside public funding, green bonds expand the financing base beyond traditional donor sources.

According to Benegiamo (2025), collectively, these instruments represent complementary pathways for delivering adaptation finance. While global mechanisms like the AF and GEF address systemic funding gaps, sector-specific funds (REF, RAFF) and capital market tools (green bonds) enhance resource diversity and flexibility. However, literature highlights challenges such as limited absorptive capacity, high transaction costs, and uneven fund access, underscoring the need for institutional strengthening and alignment with national development priorities (Rishi et al., 2025).

Economic Growth and Outlook in Sub-Saharan Africa

Sub-Saharan Africa's economic outlook for the period 2023–2025 presents a mixed picture, shaped by post-pandemic recovery, structural vulnerabilities, and rising geopolitical uncertainties. According to the International Monetary Fund (IMF), growth in the region rebounded to 3.9% in 2023 and is projected to reach 4.1% in 2025, driven by improved commodity exports, public investment in infrastructure, and gradual stabilization of inflation (IMF, 2025). However, the recovery remains highly uneven across countries and sectors. Resource-rich countries like Nigeria and Angola benefit from favorable oil prices, while diversified economies such as Kenya and Côte d'Ivoire show resilience through services and agriculture. Yet, several fragile and conflict-affected states continue to lag behind, facing double-digit inflation, fiscal stress, and weak investor confidence (Kohnert, 2025). Moreover, the region's per capita GDP growth remains low, limiting tangible improvements in living standards.

The literature identifies demographics as both an opportunity and a constraint. Sub-Saharan Africa is projected to be home to over 2.5 billion people by 2050, with a youth-dominated population (Foster & Hall, 2025). This demographic dividend, if well harnessed, could spur productivity, innovation, and domestic consumption. Yet, it also demands massive investments in education, health, and job creation, sectors currently underfunded and inefficiently managed. One major concern in the recent literature is the debt sustainability challenge. Many SSA countries entered the post-COVID era with elevated debt levels. By 2024, over 20 countries had breached the 55% debt-to-GDP threshold considered sustainable for low-income nations (World Bank, 2024). Rising global interest rates, coupled with currency depreciation and climate shocks, exacerbate fiscal fragility and reduce policy space for growth-enhancing expenditures.

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Climate change further compounds economic risks. Studies show that rising temperatures and erratic rainfall are already impacting agricultural yields, which constitute the livelihood of 60% of the SSA population (Murungi et al., 2025). Infrastructure degradation due to flooding, coastal erosion, and desertification imposes high adaptation costs and deters foreign investment. These challenges position climate adaptation as both a necessity and a strategic enabler of sustained growth.

Digitalization and energy access are frequently cited as critical drivers of future growth. Yet, gaps persist. As of 2023, internet penetration stood at 33% and access to electricity at 48% in rural areas, significantly below global averages (Falchetta et al., 2024). Without addressing these bottlenecks, SSA may struggle to participate effectively in the global digital economy and green energy transition.

Another vital issue is trade integration. The African Continental Free Trade Area (AfCFTA), operationalized in 2021, holds transformative potential for intra-African commerce and industrialization. But implementation remains sluggish, hindered by infrastructure deficits, non-tariff barriers, and policy misalignment. Fully realizing AfCFTA's benefits could increase regional trade by over 50% and create more inclusive value chains (UNECA, 2025).

Theoretical Literature Review

The exploration of climate adaptation finance and its linkage to economic growth in Sub-Saharan Africa (SSA) demands a robust theoretical framework capable of integrating environmental vulnerabilities, institutional behaviour, and development dynamics. Several interrelated theories offer conceptual clarity, but the Sustainable Livelihoods Framework (SLF) emerges as the most suitable underpinning theory for this study. Complementary frameworks such as the Endogenous Growth Theory, Environmental Kuznets Curve (EKC), and Climate Justice Theory also offer critical insights into specific dimensions of the finance-growth-climate nexus.

Sustainable Livelihoods Framework (SLF)

The Sustainable Livelihoods Framework developed by the UK Department for International Development (DFID) provides a holistic model for understanding the impacts of climate change and adaptation finance on livelihoods and economic resilience (Chambers & Conway, 1992; DFID, 1999). SLF posits that people draw on a diverse range of capital assets—human, natural, physical, financial, and social—to sustain their livelihoods in the face of environmental and economic shocks.

Concerning climate adaptation finance, SLF is particularly relevant because it highlights how targeted funding can strengthen adaptive capacities by enhancing these asset bases. For instance, financial flows that improve irrigation systems (physical capital) or support agricultural training (human capital) contribute not only to resilience but also to inclusive economic growth. As argued by Gemayel et al. (2025), adaptation finance must be context-sensitive and directed at the asset base most affected by climatic stresses in SSA, such as land degradation or water scarcity.

Moreover, the SLF also accounts for vulnerability contexts and institutional processes, two critical dimensions often overlooked in traditional economic models. Adaptation finance in SSA often fails not because of scarcity but due to weak institutions and poor targeting (Lee et al., 2025). The SLF underscores the need for institutional reform and participatory planning as preconditions for effective adaptation spending.

Endogenous Growth Theory

Endogenous Growth Theory (EGT) provides an important macroeconomic lens through which adaptation finance can be viewed as a productive investment, not just a

cost. EGT argues that economic growth is primarily driven by internal factors such as human capital development, innovation, and policy (Romer, 1990). When adaptation finance is used to build climate-resilient infrastructure or improve agricultural productivity, it effectively increases total factor productivity and spurs long-term growth (Byaro & Rwezaula, 2025).

This theory also reinforces the idea that adaptation finance should not be treated as consumption or aid but rather as capital formation. The World Bank (2024) supports this perspective, noting that investing in early adaptation can yield a benefit-cost ratio of up to 4:1, especially in vulnerable sectors like agriculture and energy. However, a key critique of EGT in this context is that it often abstracts from environmental constraints and ecological boundaries. While it explains growth well, it requires integration with frameworks like SLF to incorporate climate vulnerabilities.

Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve hypothesizes an inverted U-shaped relationship between environmental degradation and economic growth: in early stages of growth, environmental degradation increases, but beyond a certain income threshold, societies begin to invest in environmental protection (Grossman & Krueger, 1995).

This theory provides a valuable but controversial lens for SSA. While some upper-middle-income African economies may show signs of decoupling growth from emissions, the majority of SSA countries have not reached the income threshold for this transition. Critics argue that the EKC assumes a linear trajectory that does not account for climate-induced shocks that can derail development gains (Kohnert, 2025). Nevertheless, the theory supports the need for early climate investment to avoid irreversible environmental and economic losses.

Climate Justice Theory

Climate Justice Theory places emphasis on the ethical dimensions of climate finance. It argues that nations least responsible for climate change (such as those in SSA) should not bear the burden of adaptation alone and are therefore entitled to compensation or climate reparations from industrialized nations (Schlosberg & Collins, 2014). This theory provides a normative foundation for advocating increased adaptation finance flows to SSA. As Benegiamo (2025) notes, climate adaptation finance must be situated within a broader discourse of ecological sovereignty and distributive justice. However, while Climate Justice Theory articulates the why, it is less helpful for operationalizing the how of effective adaptation financing and growth modeling, which is where frameworks like SLF and EGT are more practical.

Institutional Theory

Institutional Theory explains how formal and informal institutions shape the access, utilization, and outcomes of adaptation finance. It posits that well-designed institutions are critical for reducing transaction costs, improving transparency, and aligning incentives (North, 1990). SSA's limited fiscal space and weak institutional frameworks often lead to inefficiencies and corruption in climate finance implementation (Taera & Lakner, 2025). Institutional quality thus acts as a mediator between adaptation finance and economic growth. This underscores the SLF's relevance, as it incorporates institutional processes into its analytical model.

Empirical Evidence

Empirical studies have shown mixed but increasingly positive associations between adaptation finance and economic growth in SSA. Akanni and Akinpelu (2025) conducted a panel data analysis covering 35 SSA countries from 2000 to 2022, assessing the impact of climate adaptation spending on GDP growth. Their findings

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suggest a statistically significant but non-linear relationship: adaptation finance promotes economic growth more effectively in countries with robust institutions and diversified economies. This aligns with the findings of Gemayel et al. (2025), who used IMF financial tracking and national account data to evaluate the scalability of climate finance in the region. Their study highlights that while adaptation finance is not a direct growth stimulus like infrastructure investment, it reduces vulnerability, especially in agriculture-dependent economies, thereby enabling more stable long-term growth trajectories.

Further empirical validation comes from Taera and Lakner (2025), who evaluated how sustainable finance instruments—such as green microloans and resilience bonds—contribute to both financial inclusion and economic performance. Using a structural equation modeling approach, they found that adaptation-focused finance has a multiplier effect on economic growth through improved livelihood resilience and enterprise productivity in rural areas. The impact of adaptation finance on growth often operates through sectoral pathways, particularly agriculture, energy, and water resources. Jallow and Jiang (2025) analyzed household-level data across five SSA countries and found that climate-resilient agricultural programs funded through adaptation channels significantly enhanced food security and increased rural household income by up to 17%. Similarly, Mugisha et al. (2025) used geospatial analysis to study urban adaptation initiatives in Kigali and Lagos. Their findings suggest that investments in flood mitigation infrastructure and urban drainage systems contributed not only to environmental resilience but also to increased land values and SME productivity.

Moreover, Adesogan et al. (2025) evaluated livestock productivity under climate-smart interventions in Ethiopia and Kenya. Their results showed that targeted adaptation interventions, such as drought-resistant feed systems and water harvesting infrastructure, contributed to both income growth and dietary diversity. These studies underscore the context-specific and indirect nature of adaptation finance's contribution to economic growth.

Several studies emphasize the mediating role of institutional capacity and governance quality in translating adaptation finance into tangible economic outcomes. Rishi et al. (2025), in their cross-country regression analysis, found that countries with higher public financial management scores are more likely to convert adaptation grants into effective development outputs. Conversely, countries with low absorptive capacities or high corruption indices experience limited returns on adaptation spending. This pattern is reinforced by the empirical findings of Okesiji (2025), who focused on decentralized renewable energy systems in low-income SSA regions. The study finds that adaptation finance is most effective in decentralized governance frameworks that allow community participation and context-specific adaptation planning. Decentralized systems not only improve local accountability but also ensure that adaptation projects align with actual climate risks and community needs.

The impact of adaptation finance also varies with climate vulnerability levels. Lee et al. (2025) conducted a comprehensive study on World Bank's adaptation finance allocation and found that funding rarely correlates with actual vulnerability metrics. Instead, politically stable and relatively better-performing countries receive the lion's share. However, empirical re-estimation using vulnerability-weighted models suggests that targeting finance based on adaptive need rather than economic size yields more equitable and impactful outcomes. Similarly, Byaro and Rwezaula (2025) examined climate vulnerability and its influence on economic recovery post-COVID-19. They

showed that countries with higher adaptation investments prior to the pandemic experienced faster economic rebounds, highlighting the protective effect of prior adaptation funding.

Despite growing attention, the empirical literature remains constrained by data quality, methodological inconsistencies, and limited longitudinal studies. Many countries in SSA lack disaggregated and up-to-date data on adaptation finance utilization. Benegiamo (2025) critiqued current evaluations for being overly focused on donor-reported disbursements rather than actual community-level outcomes. Additionally, a recurrent challenge in empirical studies is attribution—that is, distinguishing the effects of adaptation finance from broader development aid or infrastructure investment. Several studies attempt to solve this using instrumental variables (IV) or difference-in-difference (DiD) models, but these methods are not consistently applied across the literature, leading to divergent findings.

Recent studies also point to emerging innovations in climate finance that may improve empirical traceability and impact. For example, Muriithi et al. (2025) explore how blockchain-based tracking and adaptive climate insurance products are improving accountability and economic resilience among SSA farmers. These innovations offer new opportunities for empirical validation and long-term impact assessment. Furthermore, integration of satellite data and machine learning models into climate-economic modeling is an area of rapid growth. Mugisha et al. (2025) emphasize the potential of remote sensing tools to map climate risks and monitor adaptation outcomes at a micro-geographic scale. This integration promises more granular and accurate empirical insights in future studies.

3. Methodology

Sources of Data Sources and Study Model

We sourced the data for climate adaptation finance from the Climate Change Knowledge Portal (2025) and the World Development Indicators from 2012 to 2024. The SSA is taken as a regional block rather than individual countries due to data constraints. The economic growth of Sub-Sahara Africans was proxy by gross domestic product (GDP). The relationship between climate adaptation finance and economic growth is functionally expressed as: $ECG = f(CAF)$ (i)

where ECG = Economic Growth and CAF = Climate Adaptation Finance

while ECG is measured by GDP, CAF is decomposed into ADF, EFF, REF, RAF and GBI so that the relationship between ECG and CAF is econometrically expressed as:

$$GDP = \Omega + \bar{U}_1 ADF + \bar{U}_2 EFF + \bar{U}_3 REF + \bar{U}_4 RAF + \bar{U}_4 GBI + \mathcal{E} \dots\dots (ii)$$

Where: GDP = Gross Domestic Product (\$'m); ADF = Adaptation Fund (\$'m); EFF = Environmental Facility Fund (\$'m); REF = Renewable Energy Fund (\$'m); RAF = Renewable Agricultural and Forest Fund (\$'m); GRB = Green Bond Issue (\$'m); Ω = Constant; $\bar{U}_1 \dots\dots \bar{U}_5$ = Regression Coefficients; $\mathcal{E}$ = Error Term.

We employ descriptive statistics, Pearson's correlation and the Generalized Method of Moments (GMM) technique to analyze the research data. The GMM is appropriate for this time series analysis as it effectively addresses potential endogeneity and serial correlation in the model, which are common in macroeconomic data. Given the time span, GMM provides efficient and consistent parameter estimates by using instrumental variables. Its ability to handle dynamic relationships makes it particularly suitable for examining the impact of climate adaptation finance on economic growth in Sub-Saharan Africa over time. The GMM is also ideal for this study because it effectively addresses endogeneity, a common issue when explanatory variables are correlated with

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the error term. Given the dynamic nature of climate change and livelihood factors, GMM handles data efficiently by using instrumental variables to correct for bias. It also accommodates heteroskedasticity and autocorrelation, ensuring robust estimates. Moreover, GMM is well-suited for small sample sizes, making it practical for analyzing Sub-Saharan Africa's data constraints. Its ability to model complex economic relationships justifies its application in examining the effects of climate change on economic growth.

4. Results and Discussion

This section examines the specific relationship between climate-related financial funding and GDP, using econometric and statistical techniques to quantify these relationships.

Descriptive Statistics

The descriptive statistics reveal the statistical properties of each of the variables studied. Table 1 provides the summary statistics for six key variables: The table provides foundational statistical properties for the six independent variables: ADF, EFF, REF, RAF and GBI, and the dependent variable, GDP. These metrics give insight into the distribution, central tendency, dispersion, and normality of the dataset.

Table 1

Descriptive Statistics

	GDP	ADF	EFF	GBI	REF	RAF
Mean	500.4740	81.45077	237.0685	538.7846	76.91615	811.3774
Median	498.3657	84.90000	163.9500	264.0000	76.92000	610.1497
Maximum	571.0940	179.9000	621.0200	1941.000	80.21000	1557.631
Minimum	423.5253	18.11000	100.2200	10.00000	74.41000	316.3640
Std. Dev.	39.00121	52.19105	163.3843	615.0754	1.551448	439.0510
Skewness	-0.084078	0.512270	1.512679	1.323433	0.456362	0.526859
Kurtosis	2.876526	2.309339	3.889609	3.326941	2.800654	1.770084
Jarque-Bera	0.023575	0.826959	5.386442	3.852761	0.472769	1.420800
Probability	0.988282	0.661345	0.067663	0.145675	0.789477	0.491448
Obs	13	13	13	13	13	13

Source: Author (2025)

GDP has a mean value of \$500.47 million, with a median of \$498.37 million. The closeness of the mean and median indicates a relatively symmetric distribution. Its standard deviation is modest at 39.00, suggesting low volatility in GDP values across the observed countries or timeframes. The skewness (−0.08) confirms near symmetry, while the kurtosis (2.88) is just below the normal benchmark (3), suggesting that the tails of the GDP distribution are not heavily weighted (Kallner, 2018). The Jarque-Bera probability (0.988) strongly supports the null hypothesis of normality.

ADF (Adaptation Fund) shows a mean of \$81.45 million with a standard deviation of \$52.19 million, suggesting moderate spread in the data. The skewness value of 0.51 indicates a slight right-tail tendency. The kurtosis (2.31) being below 3 suggests a somewhat flat distribution, while the high JB probability (0.661) indicates that the data is acceptably normal. On its part, the EFF (Environmental Facility Fund) variable is more widely spread with a standard deviation of \$163.38 million, much larger than its mean of \$237.07 million. The maximum observed value (\$621.02million)

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is nearly six times the minimum (\$100.22 million), and the distribution is positively skewed (1.51), with moderate excess kurtosis (3.89). The JB p-value (0.068) hints at marginal normality, potentially due to the presence of outliers.

For GBI (Green Bond Issues), the statistics depict a high variability profile. The mean (\$538.78 million) is offset by a wide standard deviation of \$615.08 million. Its minimum value is just \$10 million, but the maximum rises sharply to \$1.94 billion. This variable is significantly right-skewed (1.32), and with kurtosis above 3 (3.33), it displays fat tails. The JB probability of 0.145 again points to moderate deviation from normality, but not strongly significant. REF (Renewable Energy Fund) is a very stable variable, with both the mean and median values approximately equal at \$76.92 million. Its standard deviation is only 1.55, indicating minimal variation. The slight skew (0.46) and normal-like kurtosis (2.80), along with a JB p-value of 0.789, affirm a very normal and consistent distribution. Lastly, RAF (Renewable Agricultural and Forest Fund), the largest in magnitude among the funds (mean = \$811.38 million), has a standard deviation of \$439.05 million, signaling considerable variation. Skewness and kurtosis suggest a modest rightward stretch and a flatter peak. The JB p-value (0.491) confirms approximate normality. Taken together, the descriptive statistics paint a scenario where most climate finance variables exhibit acceptable statistical properties with moderate-to-high dispersion, except for REF which is uniquely stable. GDP itself appears normally distributed, making it a sound candidate for regression modeling.

Pearson's Correlation Matrix

The correlation analysis assesses the strength and direction of the linear relationships among the variables. The main interest is how each form of climate finance correlates with GDP. The matrix is displayed in Table 2.

Table 2

Pearson's Correlation Matrix

	GDP	ADF	EFF	GBI	REF	RAF
GDP	1					
ADF	0.7533673	1				
EFF	0.0453492	0.3018872	1			
GBI	-0.143880	0.0404712	-0.203799	1		
REF	0.5092595	0.4155560	0.0554010	0.0105669	1	
RAF	0.9102786	0.8053423	0.0117040	-0.038015	0.5291286	1

Source: Author (2025)

RAF stands out with the strongest positive correlation to GDP, at 0.91, suggesting that this fund is tightly aligned with economic growth. This is a powerful indication that investments in agriculture and forestry adaptation are highly effective for promoting GDP in Sub-Saharan Africa. Following this, ADF also demonstrates a strong positive relationship with GDP at 0.75, indicating that direct adaptation interventions are also economically beneficial. REF shows a moderate correlation of 0.51 with GDP. This suggests a potential growth benefit from renewable energy investment, though possibly with indirect or long-term effects.

Conversely, EFF displays a very weak correlation with GDP, barely above zero at 0.045, suggesting limited or delayed effects of this type of funding on economic performance. Surprisingly, GBI has a negative correlation (−0.14) with GDP, implying that bond issuance might not be translating into growth or may have unintended short-term contractions due to debt servicing or delayed project implementation. Moreover,

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strong correlations between RAF and other variables, such as ADF (0.81) and REF (0.53), hint at interdependencies and potential multicollinearity, which the GMM technique addresses.

Effect of Climate Adaptation Finance on GDP

The GMM estimation tests the impact of each climate finance instrument on GDP, correcting for endogeneity and heteroskedasticity. The results of the GMM estimates are displayed in Table 3.

Table 3

Generalized Methods of Moments Estimates

Dependent Variable: GDP				
Method: Generalized Method of Moments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
ADF	0.076814	0.226406	0.339275	0.7444
EFF	-0.005403	0.032486	-0.166327	0.8726
GBI	-0.007786	0.015032	-0.517977	0.6204
REF	1.172167	3.626486	0.323224	0.7560
RAF	0.070924	0.022981	3.086201	0.0177
C	351.9885	264.3093	1.331729	0.2247
R-squared	0.844612	Mean dependent var		500.4740
Adjusted R-squared	0.733621	S.D. dependent var		39.00121
S.E. of regression	20.12927	Sum squared resid		2836.314
Durbin-Watson stat	1.315341	J-statistic		0.000000
Instrument rank	6			

Source: Author (2025)

RAF is the only variable with positive (0.0709) and statistically significant ($p = 0.0177$). This confirms that even when controlling for other variables, investment in agriculture and forestry adaptation significantly contributes to economic growth. This supports the descriptive and correlational findings. The ADF coefficient is positive (0.0768) but not significant ($p = 0.744$), suggesting that adaptation funds alone may lack immediate growth effect or are diluted by inefficiencies or project lags. Similarly, REF has a large coefficient (1.172) but with an extremely high standard error, rendering it statistically non-significant ($p = 0.756$). This could indicate large project-level variability or delayed benefits in energy projects.

The EFF and GBI coefficients are both negative (-0.0054 and -0.0078 respectively), but their p -values (0.873 and 0.620) are not statistically significant. This supports the earlier notion that these funding types may not be effectively channeled into productivity-enhancing projects, or their outcomes might manifest beyond the short-to-medium term. The constant term is large but insignificant, likely absorbing background economic variations not captured by climate finance. Model-wise, the R-squared (0.8446) and Adjusted R-squared (0.7336) suggest that the model explains a high proportion of GDP variation, which is impressive given the small sample size. The standard error of regression at 20.13 and sum of squared residuals (2836.31) show good model fit. The Durbin-Watson statistic (1.31) indicates possible positive autocorrelation in residuals, hinting at some temporal dependence or omitted variable bias. The J-statistic of 0.000 suggests the model is exactly identified, and the instruments used in the GMM estimation are valid.

Residual Normality Test

The Jarque-Bera normality test is a post-estimation test applied to verify if the residuals are normally distributed, which is a crucial assumption for inference reliability. From Figure 1, the p-value of the Jarque-Bera statistics (0.725818) is greater than the 0.05 level of significance, implying that the residuals of the GMM models are normally distributed. This further confirms the appropriateness of the research model.

Discussion of Findings

The empirical evidence derived from the Generalized Method of Moments (GMM) estimation reveals that not all climate finance flows translate equally into gross domestic product (GDP) gains. Most notably, investments in renewable agricultural and forestry sectors (RAF) was the only statistically significant contributor to GDP, while other instruments like adaptation funds, environmental facility financing, and green bond issuance exhibit limited or non-significant economic returns within the study horizon.

This finding aligns strongly Byaro et al., (2025) and Okesiji (2025) that recognized agriculture as the backbone of most Sub-Saharan African economies. Byaro, et al., (2025) emphasized that investments in climate-resilient agriculture not only boost food security but also enhance labor productivity, especially in rural economies where a majority of the workforce is employed. Their results suggest that adaptation finance channeled toward agriculture and forest-related sectors tends to produce more immediate and measurable impacts on output due to its high labor absorption and linkages to other sectors.

Similarly, Okesiji (2025) highlighted the multiplier effects of decentralized renewable energy projects on rural development and resilience. However, the current study's finding that renewable energy funds (REF) did not significantly impact GDP could be attributed to the long gestation periods of energy infrastructure projects or the inefficiency in fund deployment. This is corroborated by Falchi (2025), who notes that many Sub-Saharan green bond projects suffer from governance inefficiencies, fragmented institutional frameworks, and poor coordination, limiting their translation into real economic outcomes.

The disappointing performance of environmental facility funds (EFF) in this study also echoes broader concerns raised in the literature. Akanni et al. (2025) argued that while environmental protection investments are vital for sustainability, they often yield indirect benefits and require complementary institutional or policy interventions to affect growth measurably. This may explain why EFF, despite its strategic role in climate resilience, did not register a statistically significant impact on GDP in the short run.

Interestingly, the weak or even negative effect of green bond issuances (GBI) on GDP in the model resonates with the concerns of Falchi (2025), who examined sovereign green bonds in Nigeria and Seychelles. These authors argued that although green bonds attract international capital, they often result in increased debt burdens without a proportionate economic payoff. Moreover, they highlight that green bond markets in Africa are underdeveloped and lack transparency, further complicating their growth-enhancing potential.

Conversely, the positive and statistically significant contribution of the Renewable Agricultural and Forest Fund (RAF) supports the framework proposed by Adesogan et al. (2025), who advocate for climate-smart livestock and crop systems that are both adaptive and productive. Their empirical work suggests that the integration of climate considerations into agricultural policy is not only ecologically necessary but also

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economically advantageous. This is reinforced by the high correlation between RAF and GDP in the study, reflecting a structurally important linkage that merits further policy prioritization.

It is also important to contextualize the results with the structural dynamics of the Sub-Saharan African economy. According to Byaro and Rwezaula (2025), low levels of industrialization and capital intensity in the region mean that funds oriented toward large-scale infrastructural or technological transformations, like energy, often have delayed economic impacts. In contrast, climate finance that enhances human capital, ecosystem services, and food production may yield more immediate returns — which could explain why RAF outperformed REF and EFF in the GMM model.

Furthermore, the limited effect of the Adaptation Fund (ADF) despite its strong positive correlation with GDP might reflect bureaucratic inefficiencies or fragmented implementation. Taera and Lakner (2025) note that while adaptation funds are increasingly available, many African nations struggle with absorptive capacity and compliance with donor conditions, which hinders effective disbursement and utilization. In essence, the results suggest a recalibration of climate finance priorities in the region. Policymakers and donors should not treat all adaptation finance instruments as homogenous but rather tailor their strategies based on the sectoral absorptive capacities and growth linkages.

The overwhelming significance of RAF underscores the need for deepened investments in agriculture-based adaptation as a cornerstone of both resilience and inclusive growth. Additionally, the findings point to the importance of improving institutional governance, financial oversight, and result-based financing frameworks. As emphasized by Ikenga (2025), without robust mechanisms for accountability and outcome tracking, climate finance may fail to achieve its intended developmental outcomes, thereby undermining public and investor confidence.

5. Conclusion and Recommendations

This study critically evaluated the effect of selected climate adaptation finance instruments on economic growth in Sub-Saharan Africa using Generalized Method of Moments (GMM) estimation. The analysis revealed that among the examined variables, only the Renewable Agricultural and Forest Fund (RAF) had a statistically significant and positive effect on GDP. This finding reinforces the vital role of agricultural and forestry-based climate adaptation in enhancing economic productivity across the region. While the Adaptation Fund (ADF) and Renewable Energy Fund (REF) showed positive but statistically insignificant effects, other instruments like the Environmental Facility Fund (EFF) and Green Bond Issue (GBI) had negligible or negative associations with GDP. These results suggest that the economic efficacy of climate finance in the region is highly sector-dependent. Investments that directly influence productivity and livelihood, such as those in agriculture and forest management, are more likely to yield measurable economic returns, particularly in a region where agriculture remains a dominant economic activity.

Based on the aforementioned findings, it is recommended that, first, policy frameworks should allocate more climate finance toward agriculture and forestry adaptation projects, given their proven economic benefits. Second, institutions managing adaptation funds must streamline disbursement and project execution to enhance the effectiveness of ADF and REF resources. Third, given the weak effect of GBI on GDP, governments should enhance the transparency, project selection, and monitoring frameworks tied to green bond proceeds. Finally, there is need to strengthen

institutional capacity: Enhanced governance, accountability, and capacity-building are essential to ensure optimal utilization of climate finance.

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