

Green energy consumption and economic growth in Sub-Saharan Africa: The moderating role of financial inclusion

 Sola Oluwagbenle^{1*},  Ojo Rufus Olawumi²,  Bernard Olagboyega Muse³, Mathias Anebamine Chuba⁴,  Adesanmi Oriola Oyewole⁵

^{1,2,3,5}Department of Economics, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria; oluwagbenle.sola@bouesti.edu.ng (S.O.) olawumi.ojo@bouesti.edu.ng (O.R.O.) muse.bernard@bouesti.edu.ng (B.O.M.) adesanmi.oriola@bouesti.edu.ng (A.O.O.).

⁴Department of Economics, Achievers University, Owo, Ondo State, Nigeria; machuba@achievers.edu.ng (M.A.C.).

Abstract: The study examines the roles of financial inclusion as a moderating variable in driving green energy consumption and economic growth in Sub-Saharan Africa between 2000 and 2023, using Panel Autoregressive Distributed Lags and fixed effects models. The study established long-run relationships among green energy consumption (GEC), financial inclusion (FI), economic growth (RGDP), interest rate (RINTR), and exchange rate (EXCR). A Granger causality test was used to verify the direction and magnitude of causality among green energy consumption, financial inclusion, interest rate, exchange rate, and economic growth. The study revealed unidirectional causality from green energy consumption to economic growth, suggesting green energy consumption as a potential driver of economic growth in SSA. The Granger causality results indicate unidirectional causality from financial inclusion to economic growth, highlighting its importance in driving economic growth in SSA. Additionally, the interest rate Granger caused economic growth, suggesting that interest rates need to be carefully managed to balance economic growth and green energy transition in SSA. The results also confirm that fixed effects are statistically significant, indicating that country-specific factors play a crucial role. The findings suggest policymakers should consider country-specific contexts when promoting green energy consumption and financial inclusion policies to foster economic growth.

Keywords: *Economic growth, Financial inclusion, Fixed effects, Green energy consumption, Panel autoregressive distributed lags, and Sub-Saharan Africa.*

1. Introduction

Sustainable economic growth and energy consumption are central themes in development research, particularly for Sub-Saharan Africa (SSA), a region characterized by persistent energy poverty, low economic growth, and limited financial inclusion. Historically, economic growth has been closely linked with increased energy consumption, but this growth model has often relied on fossil fuels, contributing to environmental degradation and climate change concerns. In contrast, green energy consumption, such as solar, wind, and hydropower, offers the potential to support economic expansion while attenuating environmental impact and enhancing energy accessibility across underserved communities in SSA [1].

In Sub-Saharan Africa (SSA), economic development and sustainability are increasingly linked to energy consumption patterns and access to financial services. The region faces three major developmental challenges: persistent energy poverty, modest economic growth, and limited financial inclusion. These factors influence each other in complex ways, especially when considering the transition toward green (renewable) energy and sustainable development [2].

Green energy is central to global efforts to address climate change, reduce air pollution, and move toward sustainable energy systems. Recent global trends show massive growth in renewable and green

energy adoption, with solar and wind leading the expansion of clean electricity generation worldwide. While often used interchangeably, green energy emphasizes environmental benefits (minimal harm or emissions), whereas renewable energy focuses on the natural replenishment of the source. Not all renewable sources are always fully green if their lifecycle involves significant environmental impacts (e.g., certain biomass or infrastructure emissions). Clean energy refers to sources that produce little or no greenhouse gas emissions during use. This definition overlaps with green energy but emphasizes emission profiles over broader environmental impact [3].

Green energy production emits little to no greenhouse gases or pollutants. Most green energy sources come from natural processes that regenerate naturally, such as sunlight and wind. These energy sources support long-term energy security and help mitigate environmental degradation. Some widely recognized forms of green energy include: solar energy captured from sunlight using photovoltaic cells or solar thermal systems, wind energy generated by converting wind flow into electricity using turbines, hydroelectric power produced by harnessing the kinetic energy of flowing water, geothermal energy derived from heat stored beneath the Earth's surface, and biomass and bioenergy are organic materials processed to produce heat, electricity, or biofuels (though the environmental impact can vary depending on practices). Green growth emphasizes the harmony between economic expansion and environmental preservation, ensuring that prosperity today does not come at the expense of future generations [3].

Empirical research indicates that greater financial inclusion can reduce energy poverty by improving access to electricity and clean cooking technologies, thereby contributing to broader development goals [4]. Thus, financial inclusion intersects with both energy access and economic growth, shaping the dynamics of sustainable development.

Despite the substantial renewable energy potential in the region, adoption remains constrained by financial, institutional, and infrastructural barriers [5]. Renewable energy market penetration in SSA has been shown to improve when enabled by financial sector credit and supportive public financing, highlighting the importance of financial structures in scaling green energy initiatives [5]. In SSA, many countries historically suffer from low levels of financial inclusion due to underdeveloped banking infrastructure, limited access to formal credit, and inadequate financial literacy. However, the advent of mobile money and fintech innovations has substantially expanded participation in financial systems across the region. Studies show that enhanced financial inclusion is associated with improved economic performance. For example, research using multidimensional measures of financial inclusion found that formal financial access significantly positively influences economic growth in SSA countries [4].

Sub-Saharan Africa (SSA) continues to face persistent challenges in energy access, economic growth, and financial inclusion despite its abundant renewable energy potential and demographic advantages. While renewable energy (green energy) offers a sustainable pathway for long-term economic development, the region still exhibits one of the lowest rates of electrification globally, and a large portion of the population remains without reliable access to modern energy services. Recent International Energy Agency (IEA) reports highlight that progress in expanding electricity access has stalled in SSA, with population growth offsetting new connections and electricity costs rising faster than incomes, limiting energy affordability and usage.

While research shows financial inclusion can improve access to energy and lessen energy poverty, its role in supporting renewable energy adoption and sustainable economic growth remains underdeveloped in empirical evidence. Moreover, existing studies often examine these variables in isolation rather than jointly, yet theoretical and preliminary empirical work suggest complex interdependencies. For example, financial inclusion might moderate how renewable energy consumption contributes to economic growth or influences environmental outcomes such as carbon emissions, but these interaction effects are not well understood for SSA. Thus, the central research problem is the limited understanding of how green energy consumption, financial inclusion, and economic growth interact jointly, particularly whether and how financial inclusion strengthens or weakens the influence of renewable energy on economic growth and sustainability in Sub-Saharan Africa, as the relationship among economic growth, green energy consumption, and financial inclusion in SSA is not straightforward [6].

The most recent body of literature shows ambiguous evidence regarding the effect of financial inclusion and renewable energy on green growth [7, 8]. Some studies suggest that while financial inclusion can stimulate economic activity, it may also inadvertently increase carbon emissions if the growth generated is heavily reliant on non-renewable energy sources [6]. Conversely, evidence points to situations where financial inclusion moderates the relationship between renewable energy use and environmental outcomes, such that increased financial inclusion enhances the positive impact of renewable energy on sustainable development [6]. This complexity underscores the need to investigate how financial inclusion may moderate the link between green energy consumption and economic growth within SSA contexts.

Accordingly, this study examines the moderating role of financial inclusion in the nexus of green energy consumption and economic growth in Sub-Saharan Africa. By exploring this interaction, the research aims to contribute to the understanding of how inclusive financial systems can support sustainable energy transitions and facilitate growth that is both economically and environmentally viable in low- and middle-income settings.

The remainder of this paper is arranged in sections: Section 2 discusses the literature, including the theoretical and empirical literature. Section 3 presents the methodology, data description, models, and estimation procedures. The results are presented and discussed in Section 4. Section 5 concludes with policy recommendations.

2. Literature Review

This section reviews both empirical concepts and empirical literature linking financial inclusion with green energy consumption and economic growth.

2.1. Conceptual Review

Green energy refers to energy produced from natural sources that have minimal or no negative impact on the environment, especially in terms of greenhouse gas emissions and ecological harm. These sources are usually renewable, meaning they are naturally replenished on a human timescale, and contribute to sustainable development and climate change mitigation by reducing reliance on fossil fuels. At its core, green energy is characterized by environmental friendliness and sustainability: it is generated in ways that do not significantly harm the natural environment, and often aligns with the goal of meeting present energy needs without compromising the ability of future generations to meet theirs [9]. Financial inclusion (FI) refers to the provision of financial services to all individuals, businesses, and communities, regardless of their income level, geographic location, or social status. Financial inclusion simply means the efforts to make financial products and services accessible and affordable to all individuals, families, firms, and establishments, regardless of their personal net worth. FI is the access to and use of formal financial services by households and firms. It is seen by policymakers as a way to improve people's livelihoods, reduce poverty, and advance economic development. It is seen by policymakers as a way to improve people's livelihoods, reduce poverty, and advance economic development [10]. Financial inclusion strives to eliminate the barriers that may hinder people from participating in the financial sector, using these services to improve their lives and standard of living [11]. The World Bank [12] points out that the concept of financial inclusion could range from "access and use of services provided responsibly and sustainably" to "delivery of financial services at affordable costs to disadvantaged and low-income segments of society."

According to Karim et al. [13], financial inclusion is an important driver of economic growth. It connects individuals, families, firms, and organizations to the financial system that can help improve consumption and expenses in countries with insufficient income. Financial inclusion plays a pivotal role in growth and economic development, but only one-third of the population worldwide has no formal access to the financial system in the form of bank accounts. According to the 2018 World Bank Report, just 33% of individuals in Sub-Saharan Africa, the least banked region globally, held a bank account with

a formal financial institution as of 2017. However, the innovation of mobile money has primarily contributed to the recent increase in this percentage to 71% [14].

Financial inclusion initiatives involve microfinance programs, mobile money services, agent banking, financial education programs, and digital payment systems. These initiatives are crucial in Sub-Saharan Africa, where millions lack access to basic financial services. Over the past decade, the region has experienced significant growth in financial inclusion, primarily driven by mobile money account adoption. Key initiatives such as mobile money operations have been game-changers by providing small and medium enterprises, the poor, and rural dwellers with access to financial services and cashless systems. Policies promoting digital payments have also contributed to increased financial inclusion. Some countries in Sub-Saharan Africa have made notable progress, with account ownership rates exceeding 50%. These successes demonstrate the potential for financial inclusion to drive economic growth and poverty reduction in the region.

Financial inclusion refers to the accessibility, availability, and usage of affordable financial services, such as credit, savings, payments, and insurance, by individuals and firms. It enables broad participation in economic activities, especially for marginalized groups, rural populations, and SMEs, which traditional financial services often overlook. Financial inclusion pertains to the access, usage, and quality of financial services by individuals and businesses. Higher financial inclusion implies improved access to banking, credit, and digital financial services for households and enterprises. It can enable investments in clean technologies, energy infrastructure, and green enterprises.

Financial inclusion is the quantitative and qualitative expansion of financial instruments, services, and products that ease enterprises' and people's access to financial services and products. Additionally, financial inclusion is an integral part of the United Nations SDGs, which play a significant role in ending hunger, poverty, and inequality and promoting sustainable development [15]. The simple reason is that when people can access funds, they can invest in businesses [16-18].

Green Energy Consumption, Financial Inclusion, and Environmental Sustainability

For the promotion of economic growth, financial inclusion has emerged as a vital component of China's financial reform [19]. Historically, economic growth correlates with higher energy demand (especially fossil fuels), which increases GDP but also environmental degradation. Renewable energy consumption offers a pathway to sustainable growth by reducing carbon emissions and mitigating climate change risks. The theoretical framework supporting the moderating role of financial inclusion in the nexus between renewable energy and environmental sustainability within the remit of CO₂ emissions is consistent with the extant financial inclusion literature [20].

According to the literature, two main theoretical positions can be used to justify the relevance of financial inclusion in sustainable development outcomes: the intensive and extensive margin theoretical frameworks. The first, or intensive margin theory, asserts that when existing customers of banks or financial institutions are provided with enhanced opportunities to increase their financial resources, these resources are used to achieve various inclusive and sustainable development goals, such as funding renewable energy sources to reduce their carbon footprint. It follows that when current customers are given more financial resources by banks, these resources can be used to purchase energy channels designed to limit carbon dioxide (CO₂) emissions.

2.2. Theoretical Framework

The theoretical framework explains the underlying mechanisms and relationships among green energy consumption, financial inclusion, and economic growth by drawing on relevant theories. In this study, the nexus among these variables can be grounded in a combination of growth theories, sustainability frameworks, and financial/innovation theories as discussed below:

First, Financial Intermediation Theory has posited that financial institutions act as intermediaries between savers and borrowers, facilitating the flow of capital into productive investments. This theory underlines the critical role of banks, microfinance institutions, and other financial entities in providing capital for investments. In rural areas, financial intermediaries often face barriers in providing services

due to geographical, social, and economic challenges. However, by offering access to financial products such as loans, insurance, and savings, financial intermediaries can enable rural populations to invest in green projects, such as renewable energy systems, sustainable agriculture, and eco-friendly infrastructure [21]. Financial inclusion, in this context, refers to the extent to which rural communities can access financial products that enable investment in environmentally sustainable projects. In regions where traditional banking infrastructure is lacking, mobile banking and digital financial services have emerged as tools to overcome these barriers, allowing individuals and businesses to engage in green investments that contribute to long-term economic and environmental resilience [22].

Second, Endogenous Growth Theory posits that economic growth results from internal factors like human capital, innovation, and knowledge spillovers, rather than external forces alone. Policies that stimulate innovation and investment in productive technologies can raise long-term growth [23, 24]. From this perspective, Green energy technologies represent innovation that can enhance productivity and long-term growth by reducing energy costs and creating new industries. Financial inclusion facilitates investment in innovation by expanding access to capital and financial services for households and firms, fostering productive investment that feeds back into growth. Thus, when financial inclusion improves, resources can be mobilized more efficiently toward clean energy projects, which can generate endogenous growth through technological spillovers and capital accumulation. This theory supports the idea that financial inclusion and innovation in green energy jointly influence long-term economic growth.

Third, research on sustainable economic development highlights the Resource Efficiency Theory and the Innovation and Technological Diffusion Theory as frameworks explaining how financial inclusion and technology deployment interact: Resource Efficiency Theory asserts that sustainable development requires efficient use of natural resources, especially energy, and that financial inclusion enables investments in technologies that maximize output while minimizing environmental impact. Innovation and Technological Diffusion Theory argue that access to finance lowers barriers to adopting and diffusing green technologies (e.g., solar systems, efficient turbines), thus facilitating the transition to renewable energy and fostering green economic growth. This theory explains why financial inclusion is crucial for the sustained adoption of clean energy technologies, which in turn contribute to sustainable economic development.

Fourth, the EKC Hypothesis suggests that environmental degradation first increases with economic growth but eventually declines after a threshold as incomes rise and societies demand cleaner technologies. In the context of renewable energy, Financial inclusion may accelerate the shift toward renewable energy as incomes and access to finance improve, thereby hastening the transition through the EKC's turning point. Renewable energy consumption, supported by inclusive finance, could help countries achieve higher growth with lower environmental costs, aligning economic and sustainability goals. This model has been applied to studies linking economic growth, energy transitions, and financial sector development.

Fifth, traditional economic theories of financial development argue that well-functioning financial systems enhance economic growth by efficiently allocating savings to investment, reducing information asymmetries, and facilitating trade and entrepreneurship. The Finance-led Growth Theory by Patrick [25] explains that financial inclusion, a dimension of financial development, mobilizes savings and channels them into productive investments, including in renewable energy infrastructure. Greater access to finance reduces the cost of capital for green energy projects, stimulating investment that contributes to GDP growth. This theoretical lens underscores the intermediary role of finance in linking energy transitions to economic expansion.

Together, these hypotheses help conceptualize different pathways through which green energy consumption and economic growth interact, with financial inclusion potentially shaping the strength and direction of these relationships. The theoretical framework for this study is from the Finance-led Growth Theory by Patrick [25], which underscores the intermediary role of finance in linking energy transitions to economic expansion.

2.3. Empirical Review

Financial inclusion has been shown to influence environmental outcomes, including CO₂ emissions. In some SSA contexts, greater financial inclusion correlates with higher emissions, potentially due to increased economic activity and energy use, but also interacts with other factors to shape environmental impacts. Financial inclusion remains relatively low in SSA compared to the world average, limiting its potential to catalyze green investments. In the same vein, renewable energy (solar, wind, hydro, and biomass) is seen as key to developing a more sustainable energy mix and has been linked to economic growth and energy access improvements. However, adoption rates vary across countries and are influenced by factors like human capital, institutional quality, and financial development.

Financial institutions and private sector credit are crucial for scaling renewable energy projects and increasing adoption. Economic growth can both amplify and attenuate the impact of financial inclusion on renewable energy consumption, as growth boosts energy demand and improves the affordability of green technologies. Without strong financial inclusion and supportive policies, growth may lead to higher traditional energy consumption and emissions.

Everything associated with the green economy, whether its economic growth supports environmental correctness, hinders it, or has no effect on it, has become a hot debate among researchers. Regarding the results of these relationships, different estimations, panelists (states), and durations of studies examined show large discrepancies [26]. However, the literature reveals mixed results on the relationship among green energy consumption, financial inclusion, and economic growth across different countries and regions.

Empirical studies suggest that financial inclusion may have mixed effects on green growth. On the positive side, it facilitates the financing of clean technologies and green entrepreneurship. In consonance with these assertions, using a quantile regression and AMG techniques on a BRICS panel dataset, Dong et al. [27] reported that financial inclusion has a positive effect on green growth at lower and medium quantiles. Using a sample of G-20 countries from 1990 to 2018, Ashfaq et al. [7] stated that green economic growth and economic globalization are the major factors that foster renewable energy consumption and that they are cointegrated in the long run. In the same vein, Le and Sarkodie [28] examined the dynamic relationship between the usage of conventional and renewable energy, economic growth, and environmental quality with emphasis on emerging markets and developing economies during the period 1990–2014. The authors used a second-generation econometric technique and the Westerlund panel cointegration test to investigate the variables' long-term relationship. This was after detecting that the variables were stationary at first difference and level series using the unit root test. The Adaptive Minimum Gradient, Conditional Covariance Estimator for Mixed Graphics (CCEMG), and Mean Group (MG) estimators were also used to assess the long-run effect between the variables. It was revealed from the results that renewable energy and conventional energy use, trade openness, and capital formation, alongside government expenditure and CO₂ emissions, significantly enhance economic growth in emerging markets and developing economies (EMDEs).

A line of research explores the relationship between financial inclusion and the green economy. Notably, according to Kwon [29], financial growth might help improve green development by giving businesses access to cutting-edge energy-efficient technologies. Kazhamiaka et al. [30] studied how economic growth impacts sustainable energy sources and concluded that producing alternative sources is prohibitively costly. As a result, countries that have achieved financial inclusion can create green economic efficiency resources that have a less harmful effect on the environment. Shen et al. [31] report that findings from the GMM estimator indicate that financial inclusion improves the total factor productivity of the Chinese agriculture sector. Similarly, Wang et al. [19] find that financial inclusion improves green economic efficiency in China.

Liu et al. [32] asserted that financial inclusion is fundamental for increasing the nation's performance, and the green economy has emerged as one of the dominant factors for ecological sustainability. But how will these two factors connect? Liu et al. [32] analyzed the correlation between the two in the case of China, which is undergoing a transformation to a green economy, using state-level statistics from 2008

to 2020 to evaluate the connection between financial inclusion and the green economy. By taking into account the fast-expanding technology banking system, as well as the application of the minimum distance to the weak efficient frontier framework (MinDw), a comprehensive assessment of financial inclusion is created, as is an assessment of green economic productivity. The findings show that the expansion of financial inclusion may contribute to increased green economic proficiency, which is primarily achieved via the tightening of credit restrictions on carbon-emitting companies. The results have more consequences for the implementation of a financial development strategy and the maintenance of healthy associations between the state, banking institutions, and businesses.

Dong et al. [27] stated that the Sustainable Development Goals (SDGs) of the United Nations emphasize the need for green growth (GG), a concept that balances economic expansion with environmental sustainability. The core principles of GG are mitigating climate change, transitioning to renewable energy consumption, and engaging in sustainable consumption. They used advanced econometric techniques to investigate how financial inclusion influences GG in BRICS countries. The augment mean group (AMG) technique, complemented by the Method of Moment Quantile Regression (MMQR) approach, suggests financial inclusion increases GG in BRICS countries. The MMQR results reveal that financial inclusion fosters GG in the lower and medium quantiles. In line with the findings, financial institutions should focus on producing financial products that support the principles of green finance. This includes green stocks, sustainability funds, credit cards, bonds, and other sustainable financial products.

Araujo and Rodrigues [33] used a quantitative methodology combining regression analysis, instrumental variable techniques, and descriptive statistics to examine how financial inclusion influences the adoption of green investments in Brazil. Their research highlighted that access to financial services, including green loans and government-backed grants, allowed rural communities to invest in renewable energy solutions, sustainable farming, and eco-tourism initiatives. The study found that rural financial inclusion programs facilitated the adoption of eco-friendly technologies and practices by providing the capital needed for green investments, thereby contributing to both economic development and environmental sustainability in Brazil's rural areas.

Kariuki et al. [34] investigated the effect of financial inclusion on the adoption of green agricultural practices in rural Kenya. The methodology employed involved a combination of quantitative and qualitative research techniques, including surveys, regression analysis, and case studies. Their study found that farmers with access to financial services such as savings accounts, microloans, and insurance were more likely to invest in sustainable farming techniques, including agroforestry, organic farming, and water-saving irrigation technologies. The research suggests that financial inclusion helps mitigate financial barriers to adopting climate-smart agricultural practices, which are vital for improving food security and environmental sustainability in rural Kenya.

Wulandari and Hariyanto [35] employed a quantitative approach combining survey data, regression analysis, and financial inclusion indicators to assess the relationship between financial inclusion and the adoption of green energy investments. They examined how financial inclusion impacts investments in green energy in rural Indonesia. The study found that access to microfinance and digital financial services facilitated investments in renewable energy sources such as solar panels and mini-hydro plants. Financial products tailored to rural areas, including green loans and flexible repayment options, enabled farmers and small businesses to adopt green energy solutions. The findings suggest that expanding financial inclusion in rural Indonesia can enhance the adoption of sustainable energy technologies and reduce reliance on non-renewable energy sources.

Asongu and Odhiambo [20] aimed to enrich the existing literature on the importance of renewable energy by exploring how financial inclusion can moderate the impact of renewable energy consumption on environmental sustainability. They focused on 26 sub-Saharan African nations for the period 2004–2022, and the empirical evidence is based on interactive fixed effects and quantile regressions. The following results were established. First, financial inclusion, measured by the number of users of automated teller machines and commercial bank branches, moderates renewable energy consumption to

have an overall negative effect on carbon dioxide emissions. Second, overall financial inclusion moderates the consumption of renewable energy to generate an overall negative effect on carbon dioxide emissions in sub-Saharan African countries with medium and high pollution levels.

Bekele et al. [36] examined the dynamic relationship between renewable energy usage and environmental sustainability in Sub-Saharan African countries using heterogeneous macro-panel data analysis over the period of 2000–2023. The study used the Augmented Mean Group Estimator technique and the Granger Causality test to analyze annual data in 30 sub-Saharan African countries. According to the study's findings, using renewable energy significantly reduces greenhouse gas emissions in sub-Saharan African nations, confirming economic theory that renewable energy positively influences environmental sustainability. Additionally, a two-way nexus between renewable energy consumption and greenhouse gas emissions was revealed from the Granger Causality test.

Abbas et al. [37] explored the impact of financial inclusion on GG in twelve developing countries, which include Tunisia, Thailand, Sri Lanka, Pakistan, Kenya, Jamaica, Iran, Indonesia, India, Ethiopia, Egypt, and Armenia, from 2004 to 2023. The researchers aimed to unveil the extent to which these countries have achieved SDG 13 (Climate Action), which requires urgent action to address the threats of climate change. Similar to the current study, an index of financial inclusion was created using variables like the number of ATMs, outstanding deposits, and outstanding loans with commercial banks. Trade openness, population, and FDI were added as control variables. The FMOLS results confirmed that technological innovation, trade openness, and FDI significantly influence GG in the twelve countries. However, FDI had a more significant impact than technological innovation and trade openness. The causality flows from FDI to GG, financial inclusion to GG, and technological innovation to GG. In the same vein, Shen et al. [31] analyzed the effects of financial inclusion on GG in twenty-six Chinese cities, utilizing the GMM alongside the instrumental variable approach. Their findings revealed that technological innovation was the chief driver of GG aside from financial inclusion in the twelve Chinese cities. Also, inclusive digital finance successfully promotes agricultural productive gains in the cities.

Birou et al. [38] examined the impact of green finance (GF) and renewable energy investments (REI) on economic growth and environmental sustainability in the European Union (EU), covering 22 member states from 2000 to 2022. The research aims to assess how these factors contribute to sustainable economic expansion and ecological conservation. Using a comprehensive cross-sectional dataset, key variables such as green finance, renewable energy investment, GDP growth, and CO₂ emissions are analyzed with secondary data from sources including IRENA, Eurostat, and the World Bank. The System Generalized Method of Moments (System GMM) estimator is employed to address endogeneity concerns and ensure robust empirical findings. The results indicate that green finance plays a crucial role in accelerating the transition to sustainable energy, reducing emissions, and promoting economic growth, while investments in renewable energy drive GDP expansion, attract foreign capital, and enhance environmental quality. Additionally, foreign direct investment (FDI) and trade liberalization emerge as key enablers of sustainability, reinforcing the importance of integrating green finance policies with international economic strategies.

Said [6] examined the relationship among renewable energy, financial inclusion, and green growth in the MENA region, focusing on how financial access and the adoption of clean energy contribute to green growth. Using a dataset of 12 MENA countries from 2010 to 2023 and applying the System Generalized Method of Moments (SGMM), they examined the individual and interactive effects of financial inclusion and renewable energy on green growth. To account for the considerable heterogeneity within the region, they distinguished between countries with more inclusive financial systems and those with less inclusive systems, where financial access remains limited. Consequently, they used fixed and random effects. For the full sample, the results reveal that financial inclusion significantly reduces green growth, while renewable energy does not exert any significant effect. For the disaggregated analysis, the effects of financial inclusion and renewable energy differ across countries with more inclusive financial systems and those with less inclusive systems. Moreover, the effectiveness of these drivers is strongly influenced by institutional quality and domestic investment. For the combined effect, they found that the

interaction between financial inclusion and renewable energy promotes green growth only in countries with more inclusive financial systems, while it reduces green growth in countries with less inclusive systems. The study provides novel, region-specific evidence and offers practical guidance for policymakers to design strategies that align financial inclusion and renewable energy initiatives with long-term sustainability goals in the MENA region.

Ahunanya [39] examined the impact of financial inclusion on green investments in rural areas of Nigeria, aiming to assess how access to financial services can promote environmentally sustainable practices and economic resilience. Specifically, it investigated the extent to which financial inclusion influences green investment adoption, identified challenges faced by rural populations in accessing financial services for green projects, and explored strategies to enhance financial inclusion effectiveness in supporting sustainability initiatives. It provides a detailed empirical analysis using data from 506 individuals randomly selected from rural areas in Nigeria, employing descriptive statistics, correlation, and regression analyses to evaluate the relationship between financial inclusion, income, education, age, and green investments. The findings reveal weak and statistically insignificant correlations between financial inclusion and green investments, indicating that financial inclusion alone is insufficient to drive substantial green initiatives in rural areas. Key barriers include a lack of tailored financial products, limited financial literacy, and structural challenges within rural financial systems. The study concludes that while financial inclusion is essential for economic participation, its potential to foster green investments requires complementary measures such as policy support, financial innovation, and enhanced awareness of green opportunities.

A key empirical finding shows that financial inclusion can moderate economic growth in ways that reduce environmental harm through enhanced green energy consumption, but this is context-dependent. Aligning financial inclusion goals with energy and environmental policies can mitigate negative growth–energy dynamics and accelerate sustainable development. The interplay between green energy consumption, financial inclusion, and economic growth in Sub-Saharan Africa is complex. Conversely, Abbas et al. [37] concluded that financial inclusion hinders green growth (GG) in developing countries. These relevant studies have certain limitations, which create some research gaps in this area.

2.4. Research Gap

Although a few previous research works offer significant insights into the interrelationship among green energy, financial inclusion, and economic growth, notable gaps persist. While existing literature highlights the positive relationship between financial inclusion and green energy, several gaps remain in understanding the full scope of this impact. One significant gap is the lack of long-term studies. Many studies focus on short-term impacts, failing to capture the sustainability and long-term benefits of green investments facilitated by financial inclusion. Addressing these gaps would provide a more comprehensive understanding of how financial inclusion can effectively drive green energy consumption, helping policymakers design more targeted and impactful strategies to boost economic growth in SSA.

In addition, those studies that focused on Sub-Saharan Africa using data across the countries limited their scope and coverage to the relationship between financial inclusion and economic growth without addressing the relationship among green energy consumption, financial inclusion, and economic growth simultaneously. Most studies focus on pairwise relationships (e.g., financial inclusion with economic growth or renewable energy with growth) rather than the three-way interaction among green energy consumption, financial inclusion, and economic growth. Very few empirical works incorporate these variables simultaneously to understand their interactive dynamics. Existing empirical studies show mixed or contradictory results about the nexus among financial inclusion, renewable energy, and economic growth, especially in SSA. Therefore, this study also fills this research gap by examining the relationship among green energy consumption, financial inclusion, and economic growth, as well as further identifying the direction of causality among the three variables in Sub-Saharan Africa (SSA) countries using annual time series data spanning from 2000 to 2023.

In light of the above, this study is timely and relevant as it offers a unique viewpoint to the literature by exploring the linkages among green energy consumption, financial inclusion, and economic growth in Sub-Saharan Africa (SSA). It also examines the moderating roles of financial inclusion, which can inform integrated strategies that align financial inclusion policies, energy transitions, and growth objectives. This is crucial for achieving multiple Sustainable Development Goals (SDGs) simultaneously in SSA.

2.5. Conceptual Framework

Figure 1 presents the conceptual framework illustrating the relationship between green energy consumption and economic growth, with financial inclusion acting as a moderating variable. The framework posits that improved financial inclusion enhances the capacity of households and firms to adopt renewable energy technologies, thereby strengthening the growth effects of green energy consumption in driving sustainable economic growth.

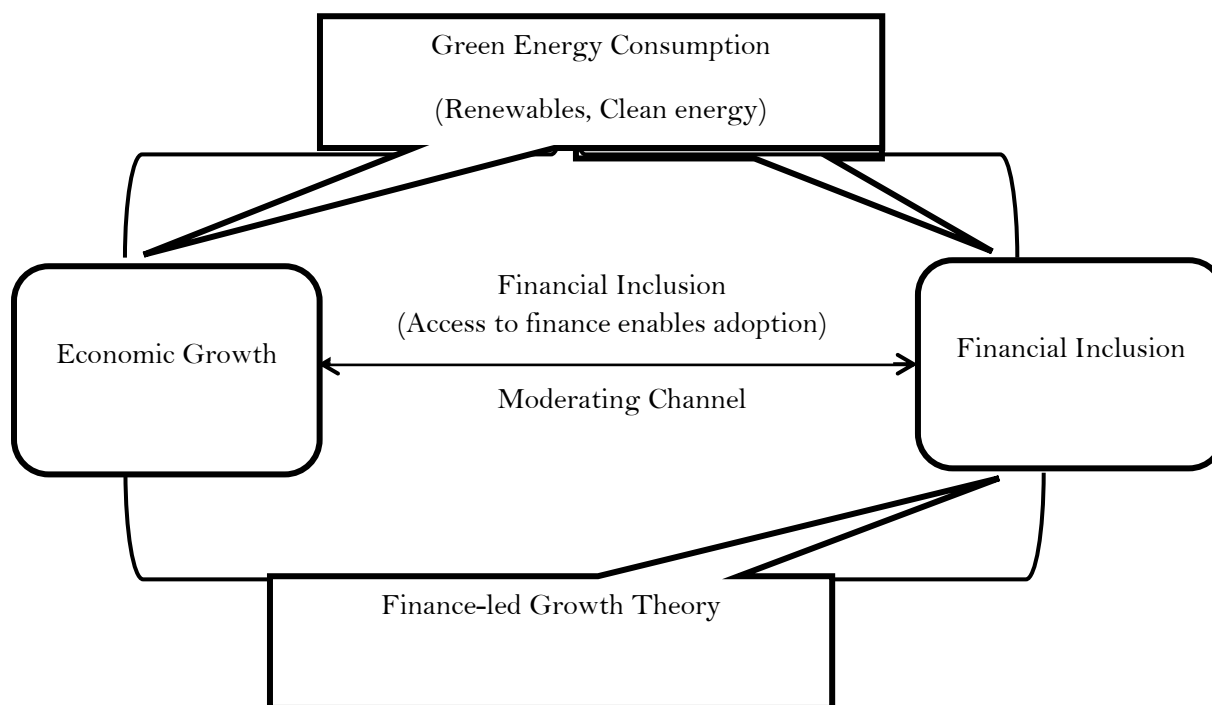


Figure 1. Green Energy Consumption, Financial Inclusion, and Economic Growth Framework.

2.5.1. Variables Classification

Independent Variables

- Green Energy Consumption
- Financial Inclusion

2.5.2. Dependent Variable

- Economic Growth
- Moderating Mechanism: Financial inclusion strengthens the impact of green energy consumption on economic growth.

FI may moderate the relationship between economic growth and green energy consumption in several ways by promoting investment in renewable energy, increasing access to credit and financial services, which can help firms and households finance clean energy technologies (e.g., solar systems, efficient

appliances), reduce energy poverty, and expand access to decentralized renewable solutions for underserved communities.

3. Sample and Empirical Approach

3.1. The Sample

To investigate the dynamic relationship among green energy consumption, financial inclusion, and economic growth in Sub-Saharan Africa, we used a sample of four key countries: South Africa, Nigeria, Ethiopia, and Kenya, over the period from 2000 to 2023. To account for heterogeneity within the SSA region, we employed a fixed effects model in the study.

3.2. Sources and Collection of Data

This study utilizes data from reputable and authoritative institutions to ensure accuracy and reliability in examining the dynamic relationship among green energy consumption, financial inclusion, and economic growth in Sub-Saharan Africa from 2000 to 2023. The principal data source comprises the World Development Indicators.

Table 1.
Identification and Description of Variables, Notations, Descriptions, Data Sources, and Expected Signs.

Variables	Notations	Descriptions / Measurements	Sources	Expected Signs
Green Energy Consumption	GEC	It refers to the use of energy from renewable or non-polluting sources, such as wind, solar, hydro, and biomass. It is a key variable for studying sustainable economic growth and environmental impacts. It is measured as the share of renewable energy in total final energy use or total energy consumption (renewable energy consumption as a percentage of total energy consumption).	WDI	Positive
Financial Inclusion	FI	It reflects how widely and deeply individuals and firms can access financial services. It is linked to investment activity, savings, and credit access, which can influence economic growth and energy financing. It is constructed as a financial inclusion index, often by aggregating multiple indicators into a composite index, such as: access indicators, number of bank branches or ATMs per 100,000 adults, and number of commercial bank branches. Its usage indicators include: share of adults with bank accounts, mobile money accounts, or credit access. The composite index, Principal Component Analysis (PCA), or other factor methods, combines multiple dimensions (access, usage, barriers) into a single financial inclusion score.	WDI	Positive
Economic Growth	RGDP	It is a measure of the total economic output of a country adjusted for inflation. It tracks growth in economic activity over time as it captures economic growth. It is measured as constant-price GDP in local currency or USD. This removes price-level changes and provides a real growth metric.	WDI	-----
Interest Rate	RINTR	It reflects the nominal interest rate adjusted for inflation. It affects the cost of borrowing and investment decisions. High real rates can constrain credit access (financial inclusion) and investment in clean energy. It is often based on central bank policy rates (e.g., lending rates) adjusted for consumer inflation. It is used as a control variable in panel regressions on economic growth and financial inclusion to capture monetary conditions.	WDI	Negative
Exchange Rate	EXCR	It measures the relative price of domestic goods to foreign goods after adjusting for inflation. It indicates competitiveness and can influence trade, investment, and energy import/export costs. It is usually expressed as an index where higher values imply currency appreciation, making domestic goods more expensive relative to foreign goods.	WDI	Negative

Note: N.B. WDI: World Development Indicators of the World Bank.

3.3. Model Specification

The current study used the theoretical underpinnings of Finance-led Growth Theory, which underscores the intermediary role of financial inclusion in linking energy transitions to economic expansion, as adapted by Ansari et al. [40]. It explores the connection among green energy consumption, financial inclusion, and economic growth, modified to include interest rates and exchange rates to capture the influence of the macroeconomic environment in the model:

$$RGDP_{it} = f(FI_{it}, GEC_{it}, RINTR_{it}, EXCR_{it}) \quad (1)$$

Where;

RGDP = Real Gross Domestic Product

GEC = Green Energy Consumption

FI = Financial Inclusion

RINTR = Real Interest Rate

EXCR = Exchange Rate

$i = (1 - 4 \text{ Countries})$

$t = \text{time series } (2000 - 2023)$

Equation 3.1 in econometrics form will be displayed as thus;

$$GDP_{it} = \alpha_0 + \alpha_1 FI_{it} + \alpha_2 GEC_{it} + \alpha_3 RINTR_{it} + \alpha_4 EXCR_{it} + \varepsilon \quad (2)$$

Where;

α_0 = Intercept

α_1 to α_4 = Parameters to be estimated

ε = Error term

3.4. Model Evaluation

We tested for multicollinearity and heteroscedasticity in this study using Breusch-Godfrey Serial Correlation and heteroscedasticity tests, respectively.

4. Results and Discussion

This section involves criteria for lag order selection, a summary of statistics, testing for stationarity, interpretation of results, diagnostic tests, and discussion of findings.

4.1. Results and Interpretation

Table 2.

Lag Order Selection.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1043.167	NA	1.04e+11	39.55349	39.73937	39.62497
1	-691.2324	624.1867*	456710.6*	27.21632*	28.33158*	27.64519*
2	-668.8450	35.48186	517164.9	27.31491	29.35955	28.10118
3	-656.4058	17.36800	887876.0	27.78890	30.76292	28.93256
4	-641.7668	17.67722	1498353.	28.17988	32.08329	29.68094
5	-617.2227	25.00724	1924337.	28.19708	33.02987	30.05554
6	-599.6674	14.57423	3754418.	28.47801	34.24019	30.69387

Note: The symbol * Indicates that lag 1 is the most suitable and best among others, satisfying the majority of the criteria.

Table 2 indicates the lag order selection needed for the results analysis to obtain correct information and achieve the study's stated objectives. The information shows that lag 1 is the most suitable among others, satisfying the majority of the criteria.

Table 3.
Descriptive Statistics.

	RGDP	FI	GEC	RINTR	EXCR
Mean	5.062500	48.74444	64.83542	4.928519	83.07674
Median	5.100000	25.80000	80.10000	5.050000	67.32000
Maximum	15.30000	142.4000	95.50000	18.20000	425.9800
Minimum	-6.000000	8.100000	7.600000	-17.10000	6.360000
Std. Dev.	3.747849	45.95083	32.77534	6.125144	96.54510
Skewness	0.087826	0.896656	-0.995575	-0.580226	1.913510
Kurtosis	3.266644	2.012694	2.215798	4.751775	6.608192
Jarque-Bera	0.407810	14.14374	18.31859	14.90186	109.5078
Probability	0.815540	0.000849	0.000105	0.000581	0.000000
Observations	96	81	96	81	95

Table 3 presents the descriptive statistics for the study. The mean ranges from 5.062500 (Real Gross Domestic Product) to 83.07674 (exchange rate). All standard deviation values are positive, indicating that skewness has both positive and negative values. Based on the Jarque-Bera test, only Real Gross Domestic Product (RGDP) is statistically normally distributed, with a p-value greater than the 5% significance level, while the remaining variables are not normally distributed.

Table 4.
Im, Pesaran, and Shin Unit Root Test.

Variable	Stat	P-value	Order of stationarity
RGDP	-2.22502	0.0130	I(0)
FI	-4.07583	0.0000	I(1)
GEC	-3.16479	0.0008	I(1)
RINT	-4.88356	0.0000	I(1)
EXCR	-2.36110	0.0091	I(1)

Table 4 presents the Im, Pesaran, and Shin Unit Root test results. It shows that only real gross domestic product (RGDP) is stationary at level I(0), while financial inclusion (FI), green energy consumption (GEC), real interest rate (RINTR), and exchange rate (EXCR) are stationary at 1st difference I(1). Based on this information, the Panel Autoregressive Distributed Lag (PARDL) model is suitable for analyzing the relationships among these variables.

Table 5.
Long-run (Pooled) Coefficients.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FI	0.047613	0.032380	1.470448	0.1475
GEC	0.020909	0.114089	0.183271	0.8553
RINTR	-0.113677	0.076686	-1.482381	0.1443
EXCR	-0.018175	0.006905	-2.631981	0.0111
C	3.698666	2.335670	1.583557	0.1194

Table 5 shows the long-run (Pooled) coefficient, where only the exchange rate (EXCR) had a long-run effect on economic growth (RGDP), while all other variables, such as financial illusion (FI), green energy consumption (GEC), and real interest rate (RINTR), did not have significant long-run effects on economic growth in Sub-Saharan Africa during the study period.

Table 6.
Short-run (Mean-Group) Coefficients.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(FI)	-0.441931	0.346676	-1.274765	0.2081
D(GEzC)	1.517460	2.479292	0.612054	0.5432
D(RINTR)	0.350500	0.170325	2.057832	0.0446
D(EXCR)	0.129478	0.447862	0.289103	0.7737
COINTEQ01	-0.868517	0.055523	-15.64240	0.0000

Table 6 presents the short-run (Mean-Group) coefficients of the study. The results indicate that only the real interest rate (RINTR) has a significant short-run impact on economic growth in the region from 2000 to 2023, while the remaining variables employed (FI, GEC, and EXCR) have insignificant impacts on economic growth. However, the results show that there is cointegration among the variables, where the Cointeq01 has a coefficient of -0.868517 and a p-value of 0.0000. Therefore, it shows that a long-run relationship is established among the variables.

Table 7.
Correlation Matrix.

	RGDP	FI	GEC	RINTR	EXCR
RGDP	1.000000	-0.017652	-0.180779	0.052359	-0.218109
FI	-0.017652	1.000000	-0.017652	0.091853	0.041057
GEC	-0.180779	-0.017295	1.000000	0.109219	0.254716
RINTR	0.052359	0.091853	0.109219	1.000000	0.055353
EXCR	-0.218109	0.041057	0.254716	0.055353	1.000000

Table 7 reveals the degree of association among the variables of interest in the study. Economic growth has a weak negative correlation (-0.218109) with the exchange rate, suggesting that exchange rate increases (depreciation) might be associated with lower real GDP. This indicates that exchange rate increases could hinder economic growth in SSA, possibly due to higher import costs and reduced purchasing power. Additionally, green energy consumption has a weak negative correlation (-0.180779), implying that green energy consumption might be associated with lower economic growth, potentially because SSA countries rely heavily on traditional energy sources, and transitioning to green energy might be costly and challenging. Similarly, financial inclusion has a very weak negative correlation (-0.017652) with economic growth, suggesting that increases in financial inclusion might be associated with lower economic growth, due to structural issues such as limited access to finance and infrastructural gaps affecting its relationship with economic growth. Conversely, the real interest rate has a weak positive correlation (0.052359) with real GDP, indicating that increases in interest rates might be associated with higher real GDP.

Table 8.
Pairwise Granger Causality Tests.

Null Hypothesis		Stat.	Prob.	Conclusion
FI does not Granger-cause RGDP	77	6.14242	0.0155	Unidirectional Causality
RGDP does not Granger-cause FI		2.31260	0.1326	
GEC does not Granger-cause RGDP	92	11.0171	0.0013	Unidirectional causality
RGDP does not Granger-cause GEC		0.21409	0.6447	
RINTR does not Granger-cause RGDP	77	5.80150	0.0185	Unidirectional causality
RGDP does not Granger-cause RINTR		0.51010	0.4773	
EXCR does not Granger-cause RGDP	90	0.62115	0.4328	No causality
RGDP does not Granger-cause EXCR		0.67577	0.4133	
GEC does not Granger-cause FI	77	3.50178	0.0653	No causality
FI does not Granger-cause GEC		0.13541	0.7139	
RINTR does not Granger-cause FI	77	0.03217	0.8581	No causality
FI does not Granger-cause RINTR		0.04628	0.8303	
EXCR does not Granger-cause FI	75	0.16762	0.6834	No causality
FI does not Granger-cause EXCR		0.26081	0.6111	
RINTR does not Granger-cause GEC	77	0.21386	0.6451	No causality
GEC does not Granger-cause RINTR		0.02452	0.8760	
EXCR does not Granger-cause GEC	90	0.00335	0.9540	No causality
GEC does not Granger-cause EXCR		0.01570	0.9006	
EXCR does not Granger-cause RINTR	75	0.20374	0.6531	No causality
RINTR does not Granger-cause EXCR		1.41883	0.2375	

Table 8 presents the pairwise causality tests. It indicates that unidirectional causality exists between financial inclusion (FI) and real GDP, green energy consumption (GEC) and economic growth (RGDP), and real interest rate (RINTR) and economic growth (RGDP). No causality is found between exchange rate (EXCR) and economic growth (RGDP), real interest rate (RINTR) and financial inclusion (FI), exchange rate (EXCR) and financial inclusion (FI), real interest rate (RINTR) and green energy consumption (GEC), or exchange rate (EXCR) and RINTR. No bidirectional causality was established among the variables during the study period.

Table 9.

Serial correlation.

H₀: There is no serial correlation

H₁: There is serial correlation

Lag	LRE* stat	Df	Prob.	Rao F-stat	Df	Prob.
1	64.00366	25	0.0000	2.845667	(25, 187.2)	0.0000
2	27.49824	25	0.3315	1.111398	(25, 187.2)	0.3332

Table 9 shows the results for serial correlation, where the p-values at lag 2 are greater than the 5% significance level, indicating that the null hypothesis (H₀) is accepted and the alternative hypothesis (H₁) is rejected. At lag 1, the p-values are less than 5% significance value. Based on this information, at lag 2, the model is valid and can be used for policy recommendations.

Table 10.

Heteroskedasticity for the joint test.

H₀: There is no heteroskedasticity

H₁: There is heteroskedasticity

Chi-sq	Df	Prob.
1019.245	975	0.1581

Table 10 presents the joint test of heteroskedasticity for the variables, with a Chi-sq value of 1019.245 and a p-value of 0.1581. Based on this finding, it is obvious that the p-value exceeds the 5% significance

level, the null hypothesis (H_0) can be accepted, and the alternative hypothesis (H_1) rejected. Consequently, the model is valid and appropriate for policy recommendations.

Table 11.

Fixed Effect Results.

H_0 : All fixed effects are zero (i.e., no individual-specific effects).

H_1 : At least one fixed effect is non-zero (i.e., individual-specific effects exist).

Dependent Variable: RGDP

Method: Panel Least Squares

Date: 02/02/26 Time: 03:44

Sample: 2000 2023

Periods included: 24

Cross-sections included: 4

Total panel (unbalanced) observations: 80

Cross-section SUR (PCSE) standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.420587	7.859902	0.944107	0.3483
FI	0.030628	0.041056	0.745990	0.4581
GEC	-0.032373	0.113124	-0.286172	0.7756
RINTR	-0.082442	0.074175	-1.111454	0.2701
EXCR	-0.022656	0.005753	-3.938422	0.0002
Effects Specification				
Cross-section fixed (dummy variables)				
R-squared	0.367009	Mean dependent var		4.411250
Adjusted R-squared	0.305469	S.D. dependent var		3.612916
S.E. of regression	3.010952	Akaike info criterion		5.137029
Sum squared resid	652.7397	Schwarz criterion		5.375232
Log likelihood	-197.4812	Hannan-Quinn criterion.		5.232531
F-statistic	5.963683	Durbin-Watson stat		1.801215
Prob(F-statistic)	0.000017			

Table 11 indicates a very small p-value ($0.000017 < 0.05$); therefore, we reject the null hypothesis (H_0), which implies that the fixed effects are statistically significant, indicating that individual-specific effects exist. This result further confirms that individual-specific effects capture unique characteristics of each country, controlling for heterogeneity. The results suggest the model fits the data, allowing for more accurate inference about the relationships among the variables in the study.

4.2. Discussion of Findings

The study reveals significant insights into the relationship between green energy consumption, financial inclusion, and economic growth in Sub-Saharan Africa (SSA). Key findings indicate the existence of long-run relationships among green energy consumption (GEC), financial inclusion (FI), economic growth (RGDP), interest rate (RINTR), and exchange rate (EXCR). These results align with recent studies by Ashfaq et al. [7], establishing a long-run relationship between green energy consumption (GEC), financial inclusion (FI), and economic growth in SSA. There is a unidirectional causality from green energy consumption to economic growth, suggesting that green energy consumption is a potential driver of economic growth in SSA. These results are consistent with recent studies, Said [6], Dong et al. [27], Shen et al. [31], Wang et al. [19], Liu et al. [32], and Kariuki et al. [34], emphasizing the critical role of financial development in fostering economic growth and renewable energy transition in SSA. The results reveal a unidirectional causality from financial inclusion to economic growth, highlighting its importance in driving economic growth in SSA. This is supported by Kariuki et al. [34] and Araujo and Rodrigues [33], who found a positive relationship between financial inclusion and economic growth in SSA. The study's findings on the importance of green energy consumption in promoting environmental

sustainability are consistent with Dong et al. [27], Asongu and Odhiambo [20], and Bekele et al. [36], who reported that green energy consumption and economic policy stability promote sustainability in SSA.

5. Conclusion and Policy Recommendations

The study establishes long-run relationships between green energy consumption, financial inclusion, interest rate, exchange rate, and economic growth in SSA. In addition, the study also reveals that the interest rate has a significant short-run impact on economic growth. The study further establishes a unidirectional causality from financial inclusion to economic growth, which highlights its importance in driving economic growth in SSA. In the same vein, the study also confirms a unidirectional causality from green energy consumption to economic growth, which suggests it as a potential driver of economic growth in SSA. Nevertheless, the significant fixed effects in the study indicate that country-specific contexts play a crucial role in promoting green energy consumption and financial inclusion in SSA. Based on the findings of the study, some policy recommendations were made. First, there is a critical need for innovative strategies to integrate environmental sustainability into financial inclusion frameworks, and broader socio-economic and policy-level factors must be considered to enhance the effectiveness of financial inclusion in promoting green energy consumption. The research underscores the need for targeted interventions and complementary measures to strengthen the link between financial inclusion and green energy consumption. Second, monetary authorities need to design low-interest loans, insurance, and savings instruments explicitly aimed at supporting green investments. Introduce flexible repayment schemes suitable for rural populations engaged in environmentally sustainable projects. Third, governments need to implement training programs focusing on green energy consumption benefits and processes, using community outreach and digital platforms to disseminate information. Fourth, given significant fixed effects, policymakers should tailor green energy consumption and financial inclusion policies to country-specific contexts in SSA. Fifth, governments in SSA should leverage financial inclusion to promote economic growth, focusing on expanding access to finance for green energy projects. Sixth, policymakers in SSA should encourage more investment in green energy technology and infrastructure to minimize dependency on fossil fuels, as this will go a long way in alleviating environmental impacts. Seventh, monetary authorities should carefully manage interest rates to balance economic growth and green energy transition in SSA.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Copyright:

© 2026 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

References

- [1] G. J. A. G. J. Ayeni, "Renewable energy and economic stability: A study of how solar power is transforming local economies in Sub-Saharan Africa," *African Journal of Stability and Development*, vol. 17, no. 1, pp. 42-66, 2025.
- [2] N. M. Mukalayiri and R. Inglesi-Lotz, "Digital financial inclusion and energy and environment: Global positioning of Sub-Saharan African countries," *Renewable and Sustainable Energy Reviews*, vol. 173, p. 113069, 2023. <https://doi.org/10.1016/j.rser.2022.113069>
- [3] P. E. Stoknes and J. Rockström, "Redefining green growth within planetary boundaries," *Energy Research & Social Science*, vol. 44, pp. 41-49, 2018. <https://doi.org/10.1016/j.erss.2018.04.030>
- [4] R. Said and A. O. Acheampong, "Financial inclusion and energy poverty reduction in sub-Saharan Africa," *Utilities Policy*, vol. 82, p. 101567, 2023.
- [5] S. F. Okereke, C. C. Onyia, and A. E. Agada, "Renewable energy financing and renewable energy market penetration in Sub-Saharan Africa," *Top Journal of Economics and Finance*, vol. 9, no. 4, pp. 37-51, 2024.

- [6] R. Said, "Financial inclusion and environmental pollution in sub-Saharan Africa: Moderating effects of economic growth and renewable energy," *Environmental Science and Pollution Research*, vol. 31, no. 43, pp. 55346–55360, 2024. <https://doi.org/10.1007/s11356-024-34785-7>
- [7] S. Ashfaq, S. Liangrong, F. Waqas, S. Gulzar, G. Mujtaba, and R. M. Nasir, "Renewable energy and green economic growth nexus: Insights from simulated dynamic ARDL," *Gondwana Research*, vol. 127, pp. 288–300, 2024. <https://doi.org/10.1016/j.gr.2023.08.014>
- [8] X. Wei *et al.*, "PolyIm: An open source polyglot large language model," *arXiv preprint arXiv:2307.06018*, 2023.
- [9] United Nations, *Sustainable development goals: Affordable and clean energy*. United Nations: United Nations Sustainable Development Goals, 2025.
- [10] S. Ratna *et al.*, "Financial inclusion: Concepts, issues and policies for inclusive growth," Asian Development Bank Institute Working Paper Series, No. 476. Asian Development Bank Institute, 2015.
- [11] Mitchell Grant, *Financial inclusion definition*. New York, USA: Investopedia, 2024.
- [12] World Bank, *Global financial development report 2014: Financial inclusion*. Washington, DC, USA: World Bank, 2014.
- [13] Z. A. Karim, R. Nizam, S. H. Law, and M. K. Hassan, "Does financial inclusiveness affect economic growth? New evidence using a dynamic panel threshold regression," *Finance Research Letters*, vol. 46, p. 102364, 2022. <https://doi.org/10.1016/j.frl.2021.102364>
- [14] A. Demirgüç-Kunt, L. Klapper, D. Singer, S. Ansar, and J. Hess, *The Global Findex Database 2017: Measuring financial inclusion and the fintech revolution*. Washington, DC, USA: World Bank, 2018.
- [15] K. Jamil *et al.*, "Do remittance and renewable energy affect CO₂ emissions? An empirical evidence from selected G-20 countries," *Energy & Environment*, vol. 33, no. 5, pp. 916–932, 2022. <https://doi.org/10.1177/0958305X211029636>
- [16] L. T. T. Tran and L. T. Le, "Financial inclusion and economic growth: An international evidence," *Emerging Markets Finance and Trade*, vol. 57, no. 1, pp. 239–263, 2021.
- [17] I. Koomson, R. A. Villano, and D. Hadley, "Effect of financial inclusion on poverty and vulnerability to poverty: Evidence using a multidimensional measure of financial inclusion," *Social Indicators Research*, vol. 149, no. 2, pp. 613–639, 2020. <https://doi.org/10.1007/s11205-019-02263-0>
- [18] T. Inoue, "Financial inclusion and poverty reduction in India," *Journal of Financial Economic Policy*, vol. 11, no. 1, pp. 21–33, 2018. <https://doi.org/10.1108/jfep-01-2018-0012>
- [19] J. Wang, X. Dong, and K. Dong, "How renewable energy reduces CO₂ emissions? Decoupling and decomposition analysis for 25 countries along the Belt and Road," *Applied Economics*, vol. 53, no. 40, pp. 4597–4613, 2021. <https://doi.org/10.1080/00036846.2021.1904126>
- [20] S. Asongu and N. M. Odhiambo, "The role of financial inclusion in moderating the incidence of entrepreneurship on energy poverty in Ghana," *Journal of Entrepreneurship in Emerging Economies*, vol. 16, no. 6, pp. 1481–1499, 2024. <https://doi.org/10.1108/JEEE-03-2023-0089>
- [21] D. W. Diamond, "Financial intermediation and delegated monitoring," *The Review of Economic Studies*, vol. 51, no. 3, pp. 393–414, 1984. <https://doi.org/10.2307/2297430>
- [22] T. Beck, A. Demirgüç-Kunt, and R. Levine, "Financial inclusion and economic development: A cross-country analysis," *Journal of Economic Growth*, vol. 24, no. 4, pp. 297–329, 2019.
- [23] P. M. Romer, "Increasing returns and long-run growth," *Journal of Political Economy*, vol. 94, no. 5, pp. 1002–1037, 1986. <https://doi.org/10.1086/261420>
- [24] R. E. Lucas, "On the mechanics of economic development," *Journal of Monetary Economics*, vol. 22, no. 1, pp. 3–42, 1988. [https://doi.org/10.1016/0304-3932\(88\)90168-7](https://doi.org/10.1016/0304-3932(88)90168-7)
- [25] H. T. Patrick, "Financial development and economic growth in underdeveloped countries," *Economic Development and Cultural Change*, vol. 14, no. 2, pp. 174–189, 1966.
- [26] A. Sharif, S. Afshan, and M. Shahbaz, "The nexus between financial development and environmental quality in OECD countries," *Journal of Cleaner Production*, vol. 227, pp. 232–241, 2019.
- [27] Q. Dong, D. Balsalobre-Lorente, and Q. R. Syed, "The critical role of financial inclusion in green growth: Evidence from BRICS countries," *Research in International Business and Finance*, vol. 76, p. 102847, 2025.
- [28] H. P. Le and S. A. Sarkodie, "Dynamic linkage between renewable and conventional energy use, environmental quality and economic growth: Evidence from Emerging Market and Developing Economies," *Energy Reports*, vol. 6, pp. 965–973, 2020. <https://doi.org/10.1016/j.egy.2020.04.020>
- [29] H. Kwon, "Financial development and green innovation: Evidence from emerging economies," *Journal of Environmental Economics and Policy*, vol. 7, no. 2, pp. 145–162, 2018.
- [30] S. Kazhamiaka, Y. Zhang, and X. Li, "Economic growth and sustainable energy transitions: Cost constraints and policy implications," *Energy Policy*, vol. 108, pp. 456–468, 2017.
- [31] Y. Shen, J. Liu, and H. Zhang, "Financial inclusion and green total factor productivity in agriculture: Evidence from China using GMM estimation," *Journal of Cleaner Production*, vol. 412, p. 137456, 2024.
- [32] Y. Liu, N. Tron, T. Phan, H. Ngo, and R. Putra, "Financial inclusion and green economy development in China: Evidence from provincial data (2008–2020)," *Sustainability*, vol. 14, no. 12, p. 7201, 2022.
- [33] L. D. Araujo and L. F. Rodrigues, "Financial inclusion and green investments in rural Brazil," *Environmental Economics and Policy Studies*, vol. 22, no. 2, pp. 247–263, 2020.

- [34] R. W. Kariuki *et al.*, "Integrating stakeholders' perspectives and spatial modelling to develop scenarios of future land use and land cover change in northern Tanzania," *PLoS One*, vol. 16, no. 2, p. e0245516, 2021. <https://doi.org/10.1371/journal.pone.0245516>
- [35] W. Wulandari and A. Hariyanto, "Financial inclusion and green energy investments in rural Indonesia," *Renewable and Sustainable Energy Reviews*, vol. 138, p. 110444, 2021.
- [36] M. Bekele, M. Sassi, K. Jemal, and B. Ahmed, "The dynamic linkage between renewable energy consumption and environmental sustainability in Sub-Saharan African countries: Heterogeneous macro-panel data analysis," *Cogent Economics & Finance*, vol. 12, no. 1, p. 2285188, 2024. <https://doi.org/10.1080/23322039.2023.2285188>
- [37] S. Abbas, M. A. Khan, S. Ali, and A. Rehman, "Financial inclusion and green growth in developing countries: Evidence from SDG 13 perspective," *Environmental Science and Policy*, vol. 153, pp. 103–118, 2024.
- [38] A. Birou, Y. He, L. Xiaolan, and M. Haroon, "Green finance, renewable energy investment, and sustainable development in the European Union: Evidence from panel data (2000–2022)," *Renewable and Sustainable Energy Reviews*, vol. 189, p. 113912, 2025.
- [39] I. Ahunanya, "Financial inclusion and green investments in rural Nigeria: Implications for sustainable development," *Journal of Sustainable Finance & Investment*, vol. 15, no. 2, pp. 210–228, 2025.
- [40] M. A. A. Ansari, M. Sajid, S. N. Khan, V. M. Antohi, C. Fortea, and M. L. Zlati, "Unveiling the effect of renewable energy and financial inclusion towards sustainable environment: does interaction of digital finance and institutional quality matter?," *Sustainable Futures*, vol. 7, p. 100196, 2024. <https://doi.org/10.1016/j.sftr.2024.100196>