

Decarbonization Mechanisms and Economic Growth in Sub-Saharan Africa: Does Institutional Quality Matter?

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Abstract

This paper empirically analyses whether institutional quality matters in the relationship between decarbonization mechanisms and economic growth in Sub-Saharan Africa. The study focused on three decarbonization mechanisms: renewable energy consumption, decarbonization rate, and green technology adoption. Population, industrialization, and foreign direct investment were included as control variables. The study used secondary panel data covering the period 2000 to 2024 for Sub-Saharan African countries with available economic and environmental data. The study was anchored on the neoclassical growth model, endogenous growth theory, environmental Kuznets curve perspective, Porter hypothesis, and institutional theory. A random-effects GLS regression model was adopted after diagnostic tests supported its suitability. The diagnostic results indicated that the data were stationary and free from serious autocorrelation, heteroscedasticity, and multicollinearity problems. The findings showed that renewable energy consumption, decarbonization rate, and green technology adoption each had a positive effect on economic growth in Sub-Saharan Africa. Institutional quality had a negative direct effect on economic growth but positively moderated the relationship between each decarbonization mechanism and economic growth. The interaction model explained 80.66% of the variations in economic growth. The study concludes that decarbonization mechanisms can promote economic growth in Sub-Saharan Africa, but the strength of this effect depends on the quality of institutions in each country. The study recommends that Sub-Saharan African governments strengthen institutional quality through improved governance, regulatory effectiveness, transparency, and policy enforcement so that renewable energy use, decarbonization efforts, and green technology adoption can translate into stronger and more sustainable economic growth.

Keywords: *Decarbonization mechanisms, renewable energy consumption, decarbonization rate, green technology adoption, institutional quality, economic growth, Sub-Saharan Africa.*

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1. Introduction

Economic development, energy security, climate change and transformations are all crucial in Sub-Saharan Africa. Sub-Saharan Africa produces a small amount of global greenhouse gas emissions, but because of the reliance on climate-vulnerable industries, poor adaptation and ongoing energy access issues the region is one of the most climate vulnerable. There is new evidence that for sustainable economic development to occur in Sub-Saharan Africa there needs to be an intersection between decarbonisation and development; specifically, via institutional development, innovation, renewable energy and improved technology (Adebayo et al., 2025; Ali et al., 2026; Frontiers, 2025). Institutional inefficiencies, poor infrastructure and weak regulation all limit low-carbon development options and the implementation of clean energy technologies in the region (Abbas et al., 2026; RES4Africa Foundation, 2026). A number of new studies have also revealed the importance of institutional effectiveness in energy transitions, environmental policies and innovation to inclusive and enhanced sustainability in Sub-Saharan Africa (Ali et al., 2026; Frontiers, 2025).

Consequently, the economic development of the region must include a focus upon developing solutions to issues related to energy and the climate. Studies have shown that climate change, energy shortages, and the use of carbon-intensive methods of producing goods can have a negative impact upon the economic growth of developing regions of the world (Mikhaylov et al., 2020). Additionally, studies also show that the COVID-19 pandemic created a negative shock to the energy supply of many regions, especially those that did not have the infrastructure to respond to the increased demand for energy during such a time (Aktar et al., 2021). Within Sub-Saharan Africa in particular, then, it is of interest to determine in what ways the region may be able to develop economic growth while also reducing its use of carbon-based energy sources and processes.

Decarbonization of the economies of Sub-Saharan Africa is, therefore, not just an issue related to the environment alone. Instead, as a result of the fact that many of the region's economies depend upon energy that is relatively expensive, unreliable, and often carbon-based, the process of decarbonization may lead to economic benefits to the region. Studies of the decarbonization of Africa's economy and its relationship with the environment, food systems, and the economies of the region's citizens show that there are both risks and benefits

associated with the decarbonization of those economies (Maino & Emrullahu, 2022). Furthermore, the environmental focus of decarbonization is also essential for reducing the environmental impact upon the region's most vulnerable groups of citizens (Omotoso & Omotayo, 2024). Thus, rather than discussing separately the benefits of decarbonization related to the environment, it is also important to consider the effects that such a shift may have upon the region's economy as a whole.

One of the main methods by which the region may decarbonize is through the increased use of renewable energy sources within the area. Sources of renewable energy (such as solar, wind, hydro, geothermal, and biomass) are abundant within Sub-Saharan Africa, yet the region's economies still largely utilize non-renewable energy and biomass-based fuels for energy production. Consequently, the use of renewable energy sources within the region could lead to a reduction in the environmental impact of the area, as well as lead to increased economic growth due to the reduction of energy costs for the region (Acheampong et al., 2021). Furthermore, because renewable energy systems can often be implemented directly into small businesses or even agricultural locations (off the main power grids in many regions), their use in relation to economic activities may have a similar effect (Tamasiga et al., 2022).

The second main form of decarbonization to consider within Sub-Saharan Africa is that of the decarbonization rate of the region. This rate may involve the use of energy-efficient technologies within both agricultural and industrial processes, the use of methods that reduce the emissions of the region's industries, and the increased use of modern production technologies. Each of these methods of decarbonization may lead to positive effects upon the growth of the region, although often at the cost of the initial capital requirements of implementing those changes to the region's economies. For instance, while numerous studies have indicated that the strategy of adopting carbon-neutral economies within emerging economies often relies upon the use of renewable energy, green innovations, and the modernization of technology within those economies (Behera et al., 2023), the effect of the decarbonization of Sub-Saharan Africa's economies upon its growth is of particular interest due to the region's industrialization process.

The third of the main methods of decarbonization to consider is the adoption of green technologies within the region. Such technologies may include the development of renewable energy technologies, energy-efficient equipment, processes that reduce the emissions of industrial processes, smart technologies for monitoring such processes, and green systems related to the transport of goods within the region. Studies of the impact of the adoption of such technologies into the economies of developing countries show that the increased use of green technologies is often associated with the growth of those economies and the reduction of their reliance upon natural resources for those economic activities (Tariq et al., 2022). Furthermore, other studies have shown that technologies like digital tools, blockchain technology, and the implementation of platforms that enable the monitoring of green technologies and the use of green technologies for economic production have been positively associated with reductions in the emissions of those economies and increases in their production of goods (Fernando et al., 2021).

One of the main questions to ask of each of these forms of decarbonization is the role of institutions within Sub-Saharan Africa. More specifically, high levels of institutional quality are often required to enable the successful implementation of projects related to renewable energy, green technologies, and methods of decarbonization of the region's industries and economies. Thus, it is important to investigate the role of institutions in determining the successful implementation of methods related to decarbonization of Sub-Saharan African economies. Studies of the role of institutions related to environmental and natural resource policies within countries around the world have shown that high levels of institutional quality are associated with better outcomes in relation to the environment and natural resources within those countries (Asongu & Odhiambo, 2020). Thus, Sub-Saharan Africa's institutions will be examined to determine the role that they play in enabling or preventing the implementation of each of the decarbonization methods discussed above.

Empirical studies related to Sub-Saharan Africa have provided some answers to each of these questions of the impact of the methods of decarbonization within the region. For instance, numerous studies have found both positive and negative answers regarding the relationship between the use of renewable energy within a region, the development of decarbonization methods within those regions, and the growth of the economies of those countries (Diallo, 2024; Prempeh et al., 2024). Additionally, other studies of Africa and its related economies have indicated answers to each of these questions in the general responses of each economy's response to the shift towards decarbonization, though often in contradictory ways (Balsalobre-Lorente et al., 2025; Han et al., 2025). Because of these varying answers to each of the related questions, it is beneficial to perform a study that investigates these three related mechanisms of decarbonization within Sub-Saharan Africa as a whole, as a means of providing a thorough investigation of the region and its potential for future development of such methods.

This study will contribute to the existing literature in four main ways. First, it will shift the focus of existing literature on Sub-Saharan Africa from the emissions of carbon to the economic growth of the region. Second, it will investigate each of the three main methods of decarbonization for the region as potential

contributors to the economic growth. Third, it will investigate the role of institutions as a potential moderating variable in relation to each of those four factors. Finally, in conducting such a study using a panel model that includes 1,150 country-year observations over the time period from 2000 until 2024, the study will provide new and updated information to the literature on Sub-Saharan Africa and each of these related variables.

The objectives of this study are to determine the impact of the three decarbonization mechanisms on economic growth of Sub-Saharan African economies. More specifically, the study will aim to determine the effect that the consumption of renewable energy has upon the economic growth of the region; to determine the effect that the decarbonization rate within the region has upon the growth of the economy; to determine the impact that the use and adoption of green technologies within the region has upon the economic growth of the Sub-Saharan African economies; and also to determine whether the quality of the region's institutions has any impact upon each of those relationships between the three decarbonization mechanisms and economic growth of the region. The remainder of this paper is organized as follows. Section 2 presents a literature review on each of these topics and formulates hypotheses for the study. Section 3 presents the data to be used in this study, the variables to be measured, and the model that will be utilized. Section 4 presents the results of the study. Finally, Section 5 presents the conclusions of the study, recommendations based upon those conclusions, limitations to the study, and future research directions on these topics.

2. Theoretical Foundation

The study is anchored on the neoclassical growth model, endogenous growth theory, the environmental Kuznets curve perspective, the Porter hypothesis and institutional theory. The neoclassical growth model explains economic growth as a result of improvements in capital accumulation, labour force expansion and technological progress (Solow, 1956). The variables of renewable energy consumption, decarbonization rate and green technology adoption are considered to be aspects that improve the productivity of the economy. The remaining variables of population, industrialization and FDI are held as control variables in this study.

Endogenous growth theory posits that technological change and innovation are the main determinants of economic growth (Romer, 1990). The growth of green technology within the economy is, therefore, a critical part of this theory. The environmental Kuznets curve explains the impact of economic growth on environmental degradation and suggests that after a certain level of economic growth and income per capita, the rate of environmental degradation begins to decline (Grossman & Krueger, 1995). The Porter hypothesis states that environmental regulations and policies can promote the innovation and competitiveness of firms in an economy (Porter & van der Linde, 1995). Finally, institutional theory explains how the quality of an economy's institutions determines the economic and social outcomes of that economy (North, 1990).

These different theories suggest that the various decarbonization mechanisms can have both direct and conditional effects on economic growth. The introduction of renewable energy sources will increase the supply of energy and reduce the dependence of the economy on fossil fuels. The decarbonization rate will reduce the environmental degradation caused by economic activities. The introduction of green technologies will increase the innovations that are made within the economy. The institutional quality within an economy will determine the impact that these factors will have on economic growth.

2.1 Renewable Energy Consumption and Economic Growth

Due to the ability of renewable energy to provide energy security to countries and to reduce a region's dependence on imported fossil fuels, its development has become an important variable to investigate. Recent studies have examined the economic and environmental outcomes that are associated with the use of renewable energy sources in regions like Sub-Saharan Africa (Acheampong et al., 2021). For instance, Diallo (2024) determined that while renewable energy does have a positive effect upon the economies of countries within Sub-Saharan Africa, the strength of that relationship is dependent upon the quality of the institutions within those countries.

Mazorodze (2025) investigated the relationship between renewable energy consumption and green growth within several different countries in Sub-Saharan Africa. Results indicated that renewable energy consumption within these countries had the potential to enable those countries to experience green growth. Additionally, Bi et al. (2024) examined developed and developing countries alike, with the aim of recognizing the impact that the adoption of renewable energy had within each of those group of countries. As a result, the researchers determined that the Sub-Saharan African countries require to be investigated on their own within relation to their unique environments and economic conditions.

Outside of Africa, several studies have also examined the ways in which renewable energy consumption can help to support economic growth within the countries that utilize those forms of energy. For example, Gyamfi et al. (2021) have determined that the use of forms of renewable energy like hydroelectricity is associated with both economic growth and improved environmental quality within emerging economies.

Additionally, both Khan et al. (2020) and Odugbesan and Adebayo (2020) have found that the effects of renewable energy within a given country may differ from one country to the next, potentially due to existing levels of development within the economies. Moreover, Odugbesan and Adebayo (2020) additionally determined that the growth of the use of renewable energy within a country is associated with both improved environmental and economic sustainability within those economies.

Within the African continent, as well, several studies have investigated the impact of the use of renewable energy on the economic growth of those countries. For instance, He et al. (2024) determined that the growth of renewable energy within Africa is associated with both energy security and climate change objectives. In addition, both Town Carabajal et al. (2024) and Prempeh et al. (2024) have determined that the introduction of modern methods of energy access throughout Africa have the ability to transform the outcomes of both society and the economy within those countries. Furthermore, Prempeh et al. (2024) also determined that financial development within the region has an impact upon the advancements that are made in the use of renewable energy within Sub-Saharan Africa.

Based upon these research studies of economic growth and the use of renewable energy, it is evident that renewable energy consumption within Sub-Saharan Africa is likely to enhance the region's economic growth. The first of the hypotheses to test this relationship is, therefore:

H1: Renewable energy consumption has a significant positive effect on economic growth in Sub-Saharan Africa.

2.2 Decarbonization Rate and Economic Growth

Decarbonization rate refers to the speed at which economies can move towards producing and consuming less carbon-intensive products and services. This is associated with various factors such as lower emission intensity, increased energy efficiency, the use of cleaner electricity sources, and the implementation of greener transport and industrial processes. Sahoo et al. (2022) investigated how technology, population density and economic structure relate to ecological pressure. Behera et al. (2023) studied how the introduction of carbon neutrality in emerging economies relies upon the use of renewable energy and green technology.

The effect of decarbonization on economic growth is debatable. On the one hand, it is possible that decarbonization will have a positive effect on economic growth due to the increased efficiency of processes and the reduction of energy waste. On the other hand, it is also possible that decarbonization will have a negative effect on economic growth due to the high costs of initiating such changes within economies, and the inability of those economies' production systems to adapt to such changes. Baloch and Danish (2022) researched the relationship between renewable energy use, energy inequality, and consumption-based carbon emissions. Rasheed et al. (2024) investigated how industrial performance, the use of renewable energy, and the use of new technologies can impact environmental sustainability.

The decarbonization of economies is also closely related to the process of industrialization, especially in regions like Africa. Djeunankan et al. (2024) investigated the issue of energy poverty in African countries and how this impacts their industrialization efforts. Chen et al. (2025) investigated the relationship between industrialization, energy prices, renewable energy use, and urbanization in relation to the environmental impact of industrial processes in those countries. Both of these studies are relevant to the Sub-Saharan African region in particular, as the countries in that region both require industrialization, but do not want to expose their economies to high carbon emissions.

Finally, another potential benefit of decarbonization is the potential improvement in the long-term competitiveness of a country's industries. As more countries incorporate decarbonization into their global trade policies, industries will need to be decarbonized in order to access trade agreements and partnerships. Marinov (2024) researched how decarbonization can impact a country's development through issues related to competitiveness. Lu et al. (2025) investigated the relationship between renewable energy use, economic growth, and environmental policy. Balsalobre-Lorente et al. (2025) also researched issues related to decarbonization, specifically how that process can be enhanced by the use of existing policies, technologies, and production structures within a given country.

Given the knowledge of the factors related to decarbonization, the impact of decarbonization on economic growth, and the relationship of decarbonization to industrialization, it is possible to hypothesize that decarbonization will have a positive impact upon the economies of Sub-Saharan African countries. Decarbonization can provide economic growth through the reduction of pollution, energy intensity, and health costs for the region, as well as through the protection of the region against future carbon-related risks. Thus, the second research hypothesis is stated as follows:

H2: The decarbonization rate of Sub-Saharan African economies has a significant positive effect upon the economic growth of those economies.

2.3 Green Technology Adoption and Economic Growth

Green technology adoption refers to the adoption of green technologies in the areas of energy, logistics, and the environment to create low-carbon economies. The technology growth argument maintains that green technologies boost economic productivity. Teklie (2024) investigated green innovation and renewable energies in African countries and revealed that green innovation contributes to green growth in these countries. This finding supports the argument that technology plays a significant role in decarbonization of economic activities.

Green technology also promotes economic growth due to the creation of new industries and the improvement of the efficiency of existing industries. Han et al. (2025) investigated technological innovation, green technology, and their effect on the adoption of renewable energies and environmental sustainability. Their findings showed that technological innovation positively impacts environmental sustainability. Smaoui (2025) investigated the impact of renewable energy use and environmental technology innovation on economic growth in South Africa. The findings of the research showed that the two variables significantly impact economic growth in the country. Manu (2025) investigated how information technology influences environmental sustainability in Sub-Saharan Africa through green innovation and industrial structure. The findings demonstrated that the two variables significantly impact environmental sustainability in the region.

Digital finance, green finance, and sustainable investments are essential to the adoption of green technologies. Arner et al. (2020) investigated the impact of sustainability on financial technology and financial inclusion. The researchers discovered that digital finance can enable sustainable investments. Bhatnagar and Sharma (2022) reviewed the evolution of green finance. Their findings revealed that green finance enables investments in renewable energies. Tsindeliani et al. (2022) investigated how digital transformation in the banking sector can enable sustainable development in the countries in which those banks operate. Their findings revealed that digital and sustainable development are mutually enabling when properly aligned. These research findings demonstrate the enabling effect of digital finance on green and sustainable technology adoption in Africa.

However, some researchers have explored the risks associated with the adoption of green technologies. For example, Liu et al. (2022) investigated the impact of digital finance on the energy consumption of firms. Their findings revealed that digital finance significantly increases the energy consumption of firms. Firdousi et al. (2023) also investigated the impact of digital finance on energy consumption. Their findings revealed that digital finance significantly increases the emissions of firms as their energy sources are still based on fossil fuels. Polemis and Tsionas (2023) investigated the environmental costs of blockchain technology. Their findings revealed that blockchain technology has an environmental cost if it is not based on green and sustainable energy technologies. Hence, this study will investigate the adoption of green technology as the adoption of clean technology and the use of low-carbon technologies rather than digitalizing industries.

There are various applications of green technology in Sub-Saharan African economies. These include solar irrigation, solar power for cooking, mini-grids for productive use, manufacturing industries, transport industries, and the installation of smart meters in the region's industries. Ofori et al. (2022) investigated the characteristics of the investments made in Sub-Saharan African economies. The researchers discovered that the quality of the investments and the capacity of the region's economies to absorb these investments significantly impact the economic growth that they trigger in the region. Antwi et al. (2024) investigated whether green investments will promote economic growth for African nations with supportive financial and institutional frameworks. The researchers discovered that green investments can promote economic growth in African nations. Oduro et al. (2024) investigated the determinants of environmental sustainability in Africa. Their findings revealed that the sustainable development of the environment in Africa depends on the alignment of investments, institutions, and green policies.

Based on the foregoing discussion and research findings, it is evident that the adoption of green technology will promote economic growth in Sub-Saharan Africa. Hence, the third hypothesis of this study is as follows:

H3: Green technology adoption has a significant positive effect on economic growth in Sub-Saharan Africa.

2.4 Moderating Role of Institutional Quality

In addition to its direct effect on economic growth, the institutional quality of a country may also influence the growth effects of decarbonization mechanisms due to the need for certain policies and technologies to be implemented within those institutions. Appiah et al. (2024) investigated how institutional quality and carbon mitigation relate in Sub-Saharan African countries. The authors found that factors like governance, economic growth, energy use, and industrialization within these countries are consequential to the amount of carbon that they emit. Appiah et al. (2025) further investigated these findings and discovered that institutional factors are relevant to the achievement of green GDP within these countries.

The institutional quality within a country may also play a significant role in determining whether the effect of renewable energy consumption on economic growth is strengthened within that country. Almulhim (2025) researched the effects of renewable energy consumption and institutional quality within Sub-Saharan African countries on the carbon emissions that are released by those countries. The results of this research indicated that the institutional quality within these countries can have an effect upon the outcomes of the use of renewable energy. Said et al. (2024) investigated the impact that financial inclusion has upon carbon emissions within Sub-Saharan African countries, finding that factors related to governance are strongly associated with the environmental outcomes within these countries. Furthermore, countries that possess strong institutions will experience beneficial impacts from the implementation of projects based upon the use of renewable energy technologies far better than countries that lack such strong institutions.

In addition, the institutional quality within a country may also have an effect upon the way that the rate of decarbonization within that country impacts that country's economic growth. Decarbonization is a process that requires the implementation of certain policies and technologies within the country's institutions. Rafiq et al. (2025) researched the ways in which institutional and policy factors can impact the outcomes of initiatives that rely upon the use of renewable energy within the country. Al-Zubairi et al. (2024) determined that factors like financial development, the use of renewable energy, and political stability within countries have a relationship to the amount of carbon that is released from those economies, specifically within the Arab economies of the region. Thus, it can be understood that the economic growth impact of decarbonization within countries like those in Sub-Saharan Africa will be stronger in countries with stronger institutional quality.

Finally, institutional quality may also moderate the effect of decarbonization's impact upon the adoption of green technology. Countries that possess strong institutions will find beneficial outcomes from the adoption of green technology and the related industries within their economies. Bhat and Ikram (2025) determined that financial development and foreign investment can have a catalytic impact upon the carbon emissions that are released from the economies of a country. Wang et al. (2025) similarly determined that both financial and energy system factors can impact the carbon emissions of a country. Okwu et al. (2025) also found that the institutions within which a Sub-Saharan African country is structured can impact the economic growth that results from foreign investment within those countries. Thus, more green technology will be adopted in countries with strong institutions, leading to positive impacts upon economic growth.

Overall, then, it is evident that institutional quality can moderate the effect of each of the decarbonization mechanisms upon economic growth. The hypotheses that test for these relationships are as follows:

H4a: There is a significant relationship between institutional quality, renewable energy consumption, and economic growth within Sub-Saharan African countries.

H4b: There is a significant relationship between institutional quality, the rate of decarbonization within a country, and the economic growth of that country.

H4c: There is a significant relationship between institutional quality, the adoption of green technology within a country, and that country's economic growth.

2.5 Synthesis of Empirical Evidence and Hypothesis Development

Recent empirical studies have investigated the decarbonization and economic growth relationship through various channels besides energy consumption alone. Abdul-Rahim et al. (2022) have shown that digital finance systems can enable economic sustainability. Agyeman et al. (2022) showed that the debt and governance structures within African economies can influence their economic growth rates, indicating that low-carbon economies must exhibit sustainable growth rates. Ajibola et al. (2025) investigated the relationship between energy consumption and climate change within Sub-Saharan African countries. Furthermore, Almulhim (2025) investigated the relationship between renewable energy use, the development of institutions within a country, and the resultant emissions of the economy's consumption of energy.

Anchi et al. (2023) investigated how agricultural production and infrastructure within African countries can influence their industrialization processes. Antwi et al. (2024) explored the relationship between making green investments into a country's economy and its financial system and the greening of that African economy. Appiah et al. (2024) discovered that economic growth, energy use, the population of a country, and its rate of industrialization all impact the country's ability to mitigate the amount of carbon dioxide that it emits. Appiah et al. (2025) also investigated the role that different institutions within an economy can play in enabling that economy to achieve a green GDP.

Asafo-Agyei and Kodongo (2022) investigated how foreign direct investment could enable economic growth within a country only after that country had reached certain thresholds of economic and industrial development. Awad (2021) discovered that the outcomes of foreign direct investment within a country depended upon the structure and functioning of the country's institutions and factors within those countries. Ayenew (2022) found that foreign direct investment could enable economic growth within Sub-Saharan African

countries. Dinh Su et al. (2022) investigated the role that foreign financial flows have within the economic growth of a country. Joo et al. (2022) investigated the relationship between the characteristics of the country whose economic growth is to be influenced by external capital injections, and the economic growth that resulted from those external influences.

Awais et al. (2023) investigated the ways in which climate, water, and energy systems within a country could be modeled to enable sustainability planning for that economy. Bhatnagar and Sharma (2022) studied the role of green finance in enabling a country to invest in low-carbon economic processes. Feng et al. (2024) investigated the relationship between digital finance systems and the carbon emissions of individual households within a country. Tsindeliani et al. (2022) studied digital banking systems and their potential to enable sustainable development within a country. Yang et al. (2021) investigated the role of green finance and financial technology in enabling higher quality economic developments.

Koengkan et al. (2020) investigated the relationship between renewable energy use and economic growth and carbon dioxide emissions within regional economies. Gyamfi et al. (2021) investigated how the use of renewable energy and natural resources within a country can influence the outcomes of its economy and the environment. He et al. (2024) found that the adoption of renewable energy as an energy source for a country can provide benefits related to energy security for that country. Town Carabajal et al. (2024) found that the productive uses of renewable energy within a country can transform that country's rural economies. Yaï et al. (2025) investigated how the use of renewable energy and the quality of the institutions within a country impact the development outcomes in Sub-Saharan Africa.

Kihombo et al. (2021) investigated the relationship between technological innovation and the impact of that innovation on economic variables related to finance, economic growth, and the ecological impact of that economic growth. Nathaniel et al. (2021) investigated how the natural resources of a country, its level of globalization, and the level of human resources within its population can each impact that country's environmental outcomes. Odugbesan and Adebayo (2020) discovered that the financial system of a country and the FDI that enters that country can each have an impact upon the amount of carbon dioxide that is emitted by that country. Samour et al. (2022) investigated the relationship between financial system development within a country, the use of renewable energy within that country, and the impact of those factors upon the environmental quality within that country. Usman et al. (2022) studied the relationship between the use of renewable energy within a country, the innovations in technology that are utilized to enable that use, and the sustainability of the country's ecology.

Said et al. (2024) investigated the roles that renewable energy and economic growth play in determining whether the growth of a country's financial system leads to emissions of carbon dioxide into the environment. Additionally, Rafiq et al. (2025) investigated how the institutional structure of a country can impact the outcomes of its renewable energy policies. Bhat and Ikram (2025) discovered that the development of a country's financial system and the influx of FDI into that country can have an impact upon the amount of carbon dioxide that is emitted by the economy of that country. Oduro et al. (2024) investigated how the quality of the institutions within a country and the environmental policies of that country can impact that country's sustainable economic growth. Okwu et al. (2025) also investigated how the institutions within a country can influence the contributions of FDI to the economic growth of Sub-Saharan African countries.

Within the recent literature on green technology and economic green growth, authors such as Teklie (2024) have discovered that green innovation within a country, the use of renewable energy within that country, and the quality of the institutions that regulate the economy of that country all impact the growth of the economy. Han et al. (2025) found that technological innovation can enable the increase in the use of renewable energy and the sustainability of that use within a country. Smaoui (2025) determined that the innovation and development of environmental technologies within a country can improve the green growth of the economy of that country, as with South Africa. Manu (2025) studied how green innovation and the structure of an economy's industries can impact the sustainability of that economy's environmental outcomes. Zhang et al. (2025) investigated the role that green finance and the use of renewable energy can play within enabling sustainable economic growth within developing countries.

Emenekwe et al. (2022) discovered that the development of the financial system of a country can lead to an increase in the amount of carbon dioxide that is emitted by the economy of Sub-Saharan African countries. Firdousi et al. (2023) found that the use of digital finance can lead to an increase in the amount of energy that is consumed by a country that utilizes fossil fuels as its energy source. Polemis and Tsionas (2023) determined that some digital technologies have environmental consequences, especially if those technologies depend upon the use of fossil fuel power sources to enable their functions. Chamma (2024) found that climate change impacts the economic growth of Sub-Saharan Africa. Finally, Manasseh et al. (2025) determined that the environmental degradation of a country, the country's use of climate finance, and the economic growth of that country are all interconnected factors within the region. Each of these studies, therefore, justifies the need for an economic

model that considers each of these variables; both those related to decarbonization, and those related to institutional quality and sustainability.

3. Methods

3.1 Research Design and Study Scope

The explanatory panel research design was adopted in testing the hypotheses. The population to be studied was all the countries in Sub-Saharan Africa. All countries that had complete and published data for the variables under study between the years 2000 and 2024 were included for the study. The study will, therefore, be based on 1,150 country-year observations. The data to be used in the study were secondary data extracted from the World Bank DataBank and other databases containing climate and energy data. As the variables under study can be measured at the country level, their use in the study as secondary data is appropriate.

3.2 Variables, Data Sources and Sample

The dependent variable that was measured in the study is economic growth. The independent variables that was used to explain economic growth will be renewable energy consumption, decarbonization rate, and green technology adoption. Institutional quality acted as a moderating variable in the study. The variables that were controlled for in the study are the country's population, level of industrialization and the level of its foreign direct investment. The panel data structure is appropriate for this research study.

The indicator that was used to measure economic growth is the gross domestic product of the countries included in the study. The indicator that was used to measure the variable of renewable energy consumption is the amount of renewable energy consumed in kilowatt-hours. The decarbonization rate was measured using indicators of carbon dioxide emissions per capita. The adoption of green technology was measured using a dummy variable that is scored as 1 if the country scored 1 for the adoption of green technology and 0 if it did not adopt such technology. The indicator for the institutional quality will be a composite index of indicators of the country's governance. These governance indicators will include the level of political stability in the country, the degree of control of corruption, the quality of the regulatory environment, the rule of law and governance, the voice and accountability of citizens to the government and the effectiveness of the government. The other variables was measured using the number of individuals that live in the country, the level of industrialization and the share of the country's gross domestic product accounted for by foreign direct investment.

3.3 Model Specification and Estimation

The main method of data analysis that was employed in testing the research hypotheses is panel regression analysis. Model 1 will have only the control variables. Model 2 will have the control variables and the variables that explain economic growth. Model 3 will have the control variables, the variables that explain economic growth and the variable that acts as a moderating variable. Models 4, 5 and 6 will incorporate the interaction terms for each variable of the moderating variable and the explanatory variables of interest. By following this approach, it will be possible to determine the effect of each of these variables and the change in their explanatory power for economic growth after the interaction terms are incorporated into the models. Random-effects GLS was selected as the main regression model based on the result of the Hausman test which showed that the difference in the coefficients of variables between the fixed and random models is not systematic.

Table 1: Measurement of variables

Variable category	Variable	Acronym	Measurement	Expected sign	Source
Dependent variable	Economic growth	EG	Gross domestic product measured using GDP or standardized GDP indicator.	Positive	World Bank
Independent variable	Renewable energy consumption	REC	Renewable energy consumption measured in kilowatt-hours or equivalent renewable energy indicator.	Positive	World Bank
Independent variable	Decarbonization rate	DR	Carbon dioxide emissions per capita or carbon intensity indicator capturing decarbonization progress.	Positive	Climate and carbon datasets
Independent variable	Green technology adoption	GTA	Clean technology investment indicator coded 1 where adoption is recorded and 0 otherwise.	Positive	World Bank and energy datasets
Moderating variable	Institutional quality	IQ	Composite index based on regulatory quality, government effectiveness, political stability, rule of law, corruption control, voice and accountability.	Positive	World Bank governance datasets
Control variable	Population	POP	Number of people usually living in the country.	Positive	World Bank
Control variable	Industrialization	IND	Manufacturing value added or industrial share of GDP.	Positive	World Bank
Control variable	Foreign direct investment	FDI	Net FDI inflows expressed as a share of GDP.	Positive	World Bank

Source: Researcher (2026).

First, to isolate the effect of the independent variables on the dependent variable, the study controlled for several variables as suggested by empirical literature.

$$EG_{it} = \beta_0 + \beta_1 POP_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \varepsilon_{it} \dots \dots \dots 1$$

Second, the study tested for the effect of the various sub-constructs of the independent variable on the dependent variable, while incorporating the control variables into the model as shown below:

$$EG_{it} = \beta_0 + \beta_1 POP_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \beta_4 REN_{it} + \beta_5 DR_{it} + \beta_6 GTA_{it} + \varepsilon_{it} \dots \dots \dots 2$$

Third, the study tested moderating effect of institutional quality on the various sub-constructs of independent variables on the economic growth, while incorporating the control variables into the model as shown below:

$$EG_{it} = \beta_0 + \beta_1 POP_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \beta_4 REN_{it} + \beta_5 DR_{it} + \beta_6 GTA_{it} + \beta_7 IQ_{it} + \varepsilon_{it} \dots \dots 3$$

Fourth, the study tested the interaction between renewable energy consumption and institutional quality on the economic growth, while incorporating the control variables into the model as shown below:

$$EG_{it} = \beta_0 + \beta_1 POP_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \beta_4 REN_{it} + \beta_5 DR_{it} + \beta_6 GTA_{it} + \beta_7 IQ_{it} + \beta_8 REN_{it} * IQ_{it} + \varepsilon_{it} \dots \dots \dots 4$$

Fifth, the study tested the interaction between decarbonization rate and institutional quality on the economic growth, while incorporating the control variables into the model as shown below:

$$EG_{it} = \beta_0 + \beta_1 POP_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \beta_4 REN_{it} + \beta_5 DR_{it} + \beta_6 GTA_{it} + \beta_7 IQ_{it} + \beta_8 REN_{it} * IQ_{it} + \beta_9 DR_{it} * IQ_{it} + \varepsilon_{it} \dots \dots \dots 5$$

Sixth, the study tested the interaction between green technology adoption and institutional quality on the economic growth, while incorporating the control variables into the model as shown below:

$$EG_{it} = \beta_0 + \beta_1 POP_{it} + \beta_2 IND_{it} + \beta_3 FDI_{it} + \beta_4 REN_{it} + \beta_5 DR_{it} + \beta_6 GTA_{it} + \beta_7 IQ_{it} + \beta_8 REN_{it} * IQ_{it} + \beta_9 DR_{it} * IQ_{it} + \beta_{10} GTA_{it} * IQ_{it} + \varepsilon_{it} \dots \dots \dots 6$$

Where:

EG_{it} is the Economic Growth in time period "t" for the cross-sectional unit "i"

RE_{it} is the Renewable energy consumption in time period "t" for the cross-sectional unit "i"

DR_{it} is the Decarbonization rate in time period "t" for the cross-sectional unit "i"

GTA_{it} is the Green technology adoption in period "t" for the cross-sectional unit "i"

IQ_{it} is the Institutional quality in time period "t" for the cross-sectional unit "i"

FDI_{it} is the Foreign direct investment in time period "t" for the cross-sectional unit "i"

POP_{it} is the Population growth in time period "t" for the cross-sectional unit "i"

IND_{it} is the Industrialization in time period "t" for the cross-sectional unit "i"

FDI_{it} is the Foreign direct investment in time period "t" for the cross-sectional unit "i"

ε_{it} = error term, β_0 is the intercept, $\beta_1, \dots, \beta_n$ are the beta-coefficients, "i" is the cross-section units and "t" is the time period (2000 to 2024).

4. Results

4.1 Diagnostic Test Results

Before interpreting the regression results, diagnostic tests were performed. The Harris-Tzavalis panel unit-root test reveals that all variables are stationary as all p-values are below the 5% level of significance. The results indicate that there are no unit roots in the variables and the regression model is not spurious. The results of the Wooldridge test for autocorrelation indicate that $F(1,24) = 3.055$ and p-value = .0933, which is higher than the 5% level of significance, thus indicating no first-order autocorrelation. The results of the Breusch-Pagan/Cook-Weisberg test indicate that the chi-square statistic is 0.32 with a p-value of .5726, indicating that there is no serious problem with heteroscedasticity. All variance inflation factors (VIF) values are within the recommended range between 1 and 10, with the highest value of 1.30 indicating no serious problem with multicollinearity. The results of the Ramsey RESET test indicate that $F(3,1143) = 0.62$ with a p-value of .5997, indicating that the model is adequately specified. Finally, the results of the Hausman test indicate that the chi-square value is 4.79 with a p-value of .5710, indicating that the random effects model is appropriate.

Table 2: Diagnostic test results

Diagnostic area	Test applied	Key statistic/result	Decision
Stationarity	Harris-Tzavalis unit root test	All variables $p = .0000$	Variables stationary
Autocorrelation	Wooldridge test	$F(1,24) = 3.055, p = .0933$	No first-order autocorrelation
Heteroscedasticity	Breusch-Pagan/Cook-Weisberg	$\text{chi-square} = 0.32, p = .5726$	No heteroscedasticity
Multicollinearity	Variance inflation factor	$VIF = 1.05-1.30$; mean $VIF = 1.14$	No serious multicollinearity
Model specification	Ramsey RESET	$F(3,1143) = 0.62, p = .5997$	Model adequately specified
Model selection	Hausman test	$\text{chi-square}(6) = 4.79, p = .5710$	Random effects selected

Source: Researcher (2026).

4.2 Descriptive Statistics

The descriptive statistics for the Sub-Saharan African countries reveal considerable variation within the group of countries. The economic growth figures show that the mean value is $3.18e+10$ with a standard deviation of $7.54e+10$. The population mean value is $1.92e+07$ with a standard deviation of $3.04e+07$. The industrialization mean value is 10.264 with a standard deviation of 5.954. The FDI mean value is 5.713 with a standard deviation of 14.292. The mean value for the renewable energy consumption is $2.88e+08$ with a standard deviation of $1.31e+09$ (Kinuthia & Wahome, 2026)). For the decarbonization rate, the mean value is 1.001 with a standard deviation of 1.960. Finally, the green technology adoption figure has a mean value of 0.116 with no specified standard deviation. This indicates that there were few instances in which the countries within this group adopted green technologies.

Table 3: Descriptive statistics results

Variable	Obs.	Mean	Std. dev.	Minimum	Maximum
Economic growth (EG)	1,150	$3.18e+10$	$7.54e+10$	$1.60e+08$	$5.41e+11$
Population (POP)	1,150	$1.92e+07$	$3.04e+07$	82,894.03	$2.33e+08$
Industrialization (IND)	1,150	10.264	5.954	0.000	38.248
Foreign direct investment (FDI)	1,150	5.713	14.292	-47.985	100.000
Renewable energy consumption (REC)	1,150	$2.88e+08$	$1.31e+09$	$-3.08e+09$	$1.49e+10$
Decarbonization rate (DR)	1,150	1.001	1.960	0.000	12.028
Green technology adoption (GTA)	1,150	0.116	0.320	0.000	1.000
Institutional quality (IQ)	1,150	-1.169	0.987	-2.500	1.957

Source: Researcher (2026).

4.3 Correlation Results

The results of the correlation tests provide preliminary evidence of a positive relationship between the decarbonization mechanisms and the economic growth of the countries examined. The correlation between renewable energy consumption and economic growth was found to be significantly positive ($r = .3557, p < .05$). The decarbonization rate of the countries was also significantly positively correlated with economic growth ($r = .2709, p < .05$). Furthermore, the correlation between green technology adoption and economic growth was also significantly positive ($r = .1967, p < .05$). Institutional quality, however, was not significantly correlated with economic growth ($r = .0554$), though it was significantly positively correlated with both decarbonization rate ($r = .4386, p < .05$) and the adoption of green technology ($r = .1053, p < .05$).

Table 4: Pairwise correlation matrix

Variable	EG	POP	IND	FDI	REC	DR	GTA	IQ
EG	1.000							
POP	.8257*	1.000						
IND	-.0444	-.1367*	1.000					
FDI	-.1068*	-.1202*	-.0908*	1.000				
REC	.3557*	.2785*	-.0888*	-.0378	1.000			
DR	.2709*	-.0486	.1421*	.1189*	.0989*	1.000		
GTA	.1967*	.1826*	.0492	-.0396	.1155*	.0292	1.000	
IQ	.0554	-.0508	.0837*	-.0212	.0377	.4386*	.1053*	1.000

Note. * $p < .05$. *Source: Researcher (2026).*

4.4 Regression and Moderation Results

The direct-effects model had an overall R^2 of .7911, indicating that the included variables accounted for 79.11% of the observed variation in economic growth. The model was statistically significant, Wald $\chi^2(10) = 4328.38$, $p < .001$. Population had a positive and statistically significant coefficient ($B = .8071$, $p < .001$). Industrialization had a positive coefficient that was marginally significant ($B = .0273$, $p = .051$), whereas foreign direct investment had a negative and statistically significant coefficient ($B = -.0381$, $p = .006$). Renewable energy consumption had a positive and statistically significant effect on economic growth ($B = .0992$, $z = 6.96$, $p < .001$, 95% CI [.0713, .1272]); therefore, Hypothesis 1 was supported. The decarbonization rate had a positive and statistically significant effect on economic growth ($B = .3002$, $z = 21.60$, $p < .05$, 95% CI [.2730, .3275]). It had the largest coefficient among the three decarbonization mechanisms; therefore, Hypothesis 2 was supported. Green technology adoption had a positive and statistically significant effect on economic growth ($B = .1967$, $z = 6.80$, $p < .05$, 95% CI [.1400, .2534]); therefore, Hypothesis 3 was supported. Institutional quality had a negative direct effect on economic growth, but its interactions with the three decarbonization mechanisms were positive and statistically significant. The interaction between renewable energy consumption and institutional quality was positive and statistically significant ($B = .088$, $p < .05$), supporting Hypothesis 4a. The interaction between the decarbonization rate and institutional quality was also positive and statistically significant ($B = .141$, $p < .05$), supporting Hypothesis 4b. The interaction between green technology adoption and institutional quality was positive and statistically significant ($B = .070$, $p < .05$), supporting Hypothesis 4c. Model explanatory power increased from 68.66% in the control model to 79.11% after adding the decarbonization mechanisms, 79.36% after adding institutional quality, 80.05% after adding the renewable-energy interaction, 80.36% after adding the decarbonization-rate interaction and 80.66% in the final model containing the green-technology interaction. Overall, all three decarbonization mechanisms were positively associated with economic growth, and institutional quality significantly strengthened each relationship. The final interaction model explained 80.66% of the variation in economic growth.

Table 5: Direct-effects random-effects GLS regression results

Variable	Coef.	Std. Err.	z	p	95% CI
Population	.8071	.0145	55.65	.000	[.7786, .8355]
Industrialization	.0273	.0140	1.96	.051	[-.0001, .0547]
Foreign direct investment	-.0381	.0138	-2.76	.006	[-.0652, -.0110]
Renewable energy consumption	.0992	.0142	6.96	.000	[.0713, .1272]
Decarbonization rate	.3002	.0139	21.60	.000	[.2730, .3275]
Green technology adoption	.1967	.0289	6.80	.000	[.1400, .2534]
Constant	-1.24e-09	.0135	0.00	1.000	[-.0265, .0265]

Model summary: $N = 1,150$; groups = 25; within $R^2 = .7904$; between $R^2 = .9776$; overall $R^2 = .7911$; Wald chi-square(10) = 4328.38; $p < .001$. Source: Researcher (2026).

Table 6: Hierarchical regression and moderation results

Predictor	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Population	.835***	.807***	.804***	.813***	.813***	.817***
Industrialization	.070***	.027	.027*	.025	.005	.008
FDI	.826***	-.038**	-.042**	-.040**	-.042**	-.041**
Renewable energy	-	.099***	.099***	.075***	.070***	.065***
Decarbonization	-	.300***	.325***	.320***	.398***	.390***
Green technology	-	.197***	.032*	.102***	.175***	.003
Institutional quality	-	-	-.057***	-.053***	-.045**	-.033*
REC x IQ	-	-	-	.088***	.084***	.080***
DR x IQ	-	-	-	-	.141***	.101***
GTA x IQ	-	-	-	-	-	.070***
Overall R2	.6866	.7911	.7936	.8005	.8036	.8066
Change in R2	-	.1045	.0025	.0069	.0031	.0030
Wald chi-square	2510.99	4328.38	4392.11	4577.49	4665.21	4749.52

Note. * $p < .10$, ** $p < .05$, *** $p < .01$. Source: Researcher (2026).

5. Discussion

5.1 Renewable Energy Consumption and Economic Growth

The positive renewable-energy coefficient indicates that expanding renewable energy can support economic activity by improving energy availability, reducing exposure to imported fossil fuels and enabling productive off-grid uses. This result is consistent with Yai et al. (2025), Wang et al. (2025) and Kinuthia and Wahome (2026), who associate renewable-energy development with stronger and more sustainable growth outcomes. The finding supports closer integration of renewable-energy investment with industrial and enterprise-development policies in Sub-Saharan Africa.

5.2 Decarbonization Rate and Economic Growth

The decarbonization rate produced the largest coefficient among the three mechanisms. This suggests that reducing carbon intensity through energy efficiency, cleaner production and modern infrastructure may generate productivity and competitiveness gains in addition to environmental benefits. The result agrees with Marinov (2024), who links low-carbon transition measures to greater industrial efficiency and economic competitiveness.

5.3 Green Technology Adoption and Economic Growth

The positive effect of green technology adoption indicates that cleaner technologies can expand production, stimulate innovation and support economic diversification. This interpretation is consistent with Manasseh et al. (2025) and Teklie (2024), who emphasise the role of green innovation in sustainable growth. However, the binary measure used in this study captures the presence rather than the intensity or quality of adoption, so the magnitude should be interpreted cautiously.

5.4 Moderating Role of Institutional Quality

Although institutional quality had a negative direct coefficient, all three interaction terms were positive and statistically significant. The appropriate interpretation is therefore conditional: stronger institutions enhance the growth benefits of renewable energy, decarbonization and green technology rather than necessarily producing an independent positive effect in the estimated model. This finding is consistent with Diallo (2024), Appiah et al. (2025) and Kinuthia et al. (2025), and underscores the importance of regulatory effectiveness, policy continuity, transparency and credible enforcement.

6. Conclusion

This study aimed to examine the decarbonization mechanisms and their effect on the economic growth in Sub-Saharan Africa with specific attention to whether the quality of the institutions in these countries matters. The study focuses on three different variables that are thought to explain the impact of decarbonization on the economic growth of these countries: the consumption of renewable energy, the rate of decarbonization, and the adoption of green technology in the region. Additional variables that were controlled for in this analysis include

the population, the level of industrialization, and the level of foreign direct investment in Sub-Saharan African countries. The quality of the institutions in these countries was examined as a moderating variable. Annual secondary panel data between the years 2000 and 2024 were analyzed using random effects GLS regression to determine the relationships between the variables of interest. The analysis used 1,150 country-year observations to arrive at statistically significant results.

The results of the study show that renewable energy consumption has a positive and statistically significant effect on the economic growth of Sub-Saharan African countries. This finding indicates that renewable energy use is not just an environmental necessity but also contributes to the economic growth of these countries. The implications of this study suggest that the use of renewable energy should be encouraged in various economic and industrial activities within these countries to promote economic growth.

The rate of decarbonization was also found to have a positive and statistically significant effect on the economic growth of Sub-Saharan African countries. This factor had the strongest relationship with economic growth. The findings of this study imply that the countries that are working towards decarbonization are experiencing economic growth as a result. The implication of this result is that decarbonization should be incorporated into the economic and development plans of these countries to promote economic growth.

The adoption of green technology was also found to have a positive and statistically significant effect on the economic growth of Sub-Saharan African countries. The findings of this study indicate that encouraging the adoption of green technology is likely to result in economic growth. The implications of this result are that the governments of these countries should work to encourage the adoption of green technology through various incentives for private businesses. These small and medium sized businesses should also be included in these efforts to promote the adoption of green technology within the region.

The results that demonstrate that the quality of the institutions in Sub-Saharan African countries matters indicate that the effect of the other variables on the economic growth of the region is positively moderated by the quality of the institutions in those countries. This result indicates that the use of clean energy, the decarbonization of the region's industries, and the adoption of green technologies will have a greater impact on the economic growth of the region if the institutions in these countries are of higher quality. Implications from this result are that the Sub-Saharan African countries should work to strengthen the quality of their institutions in order to allow for an improved impact of these decarbonization and energy-related initiatives on their economies.

7. Policy Implications and Recommendations

Based on the conclusions of this study, the governments of Sub-Saharan African countries should increase their investment in the generation of renewable energy within the region. The governments should formulate policies that encourage the increase in the use of renewable energy for various economic and industrial activities. Furthermore, these governments should work to incorporate decarbonization into their economic policies and strategies for promoting economic growth.

In addition, Sub-Saharan African countries should increase their focus on decarbonization as a means of promoting economic growth within their regions. Furthermore, these countries should increase their focus on the adoption of green technology as a means of increasing economic activity and growth within their economies. Finally, the governments of these countries should work to improve the quality of their institutions in order to improve the impact that their decarbonization and energy policies have upon the economies of their countries.

8. Limitations and Future Research

The findings should be interpreted in light of four limitations. First, the study relied on secondary data whose measurement may vary across Sub-Saharan African countries. Second, green technology adoption was represented by a binary indicator that could not capture the intensity, quality or diversity of technology use. Third, country-level observations concealed important sectoral and firm-level differences. Fourth, the random-effects specification may not fully account for persistence, endogeneity, non-linear relationships or cross-country spillovers.

Future research should employ sector- or firm-level data and more comprehensive measures of green technology adoption to capture variations concealed by country-level indicators. Subsequent studies could apply dynamic

panel, threshold, quantile or spatial econometric models to address endogeneity, non-linearity and cross-country spillover effects. Comparative country studies could also disaggregate institutional quality to establish which governance dimensions strengthen the contribution of renewable energy, decarbonization and green technology to economic growth.

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