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Green Investment and Economic Growth in Sub-Saharan Africa: Short-Run Costs and Long-Run Gains

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Abstract

This study examines the effect of green investment on economic growth in sub-Saharan Africa (SSA) from 1990 to 2023. Annual panel time series data was utilized, focusing on Green Investment (GIN), Economic Growth (DGDP), Gross Capital Formation (DGCF), Labour Force (LBF), Foreign Direct Investment (FDI) and Carbon Emission (CO_2). A second-generation panel stationarity and cross-sectional dependency test was employed to account for spillover effects between economic growth and green investment. The result of the study shows that in the short-run green investments has a significant effect on economic growth, with a coefficient of -17.6 meaning that in an initially green investment will reduce the output due to the cost of transition from carbon to zero carbon sources of energy. In contrast, the long-run results show that green investment positive affects economic growth, with a coefficient of 10.41 due to the decrease in the cost of production as a utilization zero emission sources of energy. Additionally, the Dumitrescu and Hurlin Granger causality test reveals bi-directional causality between green investment and economic growth. Based on the findings, the study recommends that countries should prioritize to enhance both green investment and economic growth in SSA, Improving Access to clean energy, establishing a regional green energy forum that would promote and protect sustainable development initiatives across the region.

Keywords

Economic Growth, Green, Investment, Sustainable Energy Transition, Decoupling Carbon Emissions from Economic Growth

1. Introduction

In recent decades, green investments have emerged as a critical mechanism for advancing both economic transformation and environmental sustainability globally. Green investments typically target sectors such as renewable energy, clean technologies, energy efficiency, and sustainable infrastructure, all of which are integral part of transition toward a low-carbon, resource-efficient future. In developed and emerging economies green investments have not only driven economic growth but also addressed pressing environmental challenges, such as climate change, resource depletion, and pollution**.** The statistical reports also reveal that European countries are the highest in the world leading in mitigation of carbon emission (CO_2) through green investment and renewable energy consumption in the year 2020. For instance Germany, 45.3% of their energy are from renewable sources with a target of 100% green power by 2035. Denmark targeted improved green energy consumption by 70% from 1990 to 2030. More than 75% of the target was achieved through green investment and renewable energy consumption. Likewise, Norway also has 98% of its energy consumption that comes from renewable sources [1] .

According to the Economic Outlook 2022, carbon emissions in Sub-Saharan Africa (measured in kilotons and metric tons per capita) indicate that over the past three decades (1990-2020), environmental pollution has steadily increased alongside economic growth. In 1990, total carbon emissions reached 401,805.07 kilotons, with per capita emissions at 0.78 metric tons. By 2000, total emissions had risen to 498,620.96 kilotons, but per capita emissions had declined slightly to 0.74 metric tons, a decrease of approximately 0.04 metric tons per person. In 2010, carbon emissions rose again to 692,188.10 kilotons, with per capita emissions rising to 0.79 metric tons. However, by 2020, total emissions had risen further to 760,868.11 kilotonnes, but per capita emissions had fallen to 0.66 metric tons, with per capita emissions falling by 0.13 metric tons between 2010 and 2020 [2].

The SSA area boasts abundant natural assets yet faces substantial socioeconomic issues alongside severe ecological problems. Despite possessing significant quantities of sustainable energy sources like solar, wind, and hydroelectric power in several Sub-Saharan African nations, these regions continue to rely extensively on fossil fuels such as coal, natural gas, and metals for their primary energy needs. Despite its immediate financial benefits, this dependency leads to environmental harm and worsens socioeconomic issues like poverty and joblessness. The dilemma caused by industrial activities leading to environmental harm highlights the urgent necessity for separating economic progress from ecological degradation [3]. Despite efforts by SSA towards implementing eco-friendly initiatives for promoting environmental sustainability, its less developed economic infrastructure, restricted availability of funds, inadequate legal oversight mechanisms, and insufficient technical capabilities hinder substantial expansion of green investment opportunities.

Despite significant contributions by green investment efforts across various parts of the world, notably in developed nations like those in Europe and Asia-Pacific countries including China and India, current research still lacks substantial evidence regarding its effects specifically within Sub-Saharan Africa. Green investment ties lack clarity regarding their impact on economic expansion within Sub-Saharan Africa; consequently, scant research has focused on assessing the efficacy of environmental initiatives there. The SSA's dependence on extractive sectors hinders the effectiveness of green investment in fostering economic development alongside preserving ecological balance [4].

Across several SSA nations such as Nigeria, South Africa, Angola, Botswana, and Kenya, reliance on renewable energies varies according to economic status. Statistical data indicates an association between average personal earnings and greenhouse gas emissions as well as investments in environmental sustainability. By 1980, personal disposable income rose by $725 annually compared to previous years due to a growth rate of 23% in Gross Domestic Product. Forty-four percent specifically. By 1990, the annual Gross Domestic Product had dropped by 14%. In the year 2000, there was an equal distribution between per capita income and the proportion of total yearly economic output as measured by GDP. From 2015 through 2022, however, improvements were noted; specifically, the average individual's disposable income rose significantly to reach approximately $1,690 annually despite steady increases in overall productivity rates over this period. A 64-percentage point decrease indicates significant underdevelopment concerning infrastructure; this results in substantial ecological issues like heavy air pollution due to excessive emissions, untreated sewage, sulfur oxides contributing further detrimental effects on public health [5].

Despite its potential for sustainable growth, the economic environment of Sub-Saharan Africa continues to be constrained by insufficient investment opportunities, elevated financing costs, and an absence of suitable financial tools tailored for environmental initiatives. The fiscal limitation hampers efforts in expanding green initiatives and fostering environmentally friendly development. Nevertheless, advancements in technology continue to be insufficient for promoting sustainable development within Sub-Saharan Africa's less developed regions. Areas experience insufficient R&D funding, restricted technical capabilities, and underdeveloped infrastructures, hindering the implementation and expansion of eco-friendly innovations [6]. The advancement of regional cooperation offers substantial promise in tackling those issues. A significant portion of Social Security Administration's environmental concerns include topics like global warming, exhaustion of natural resources, and intercontinental contamination. Cooperation at regional levels enables exchange of assets like materials, expertise, and innovations while boosting efficiency through larger markets and enhancing financial accessibility.

Furthermore, sub-Saharan Africa (SSA) had numerous socio-economic problems such as poverty, unemployment and environmental degradation (etc.). Despite its economic development, the region has frequently experienced environmental degradation with such end points as carbon emissions and resource exhaustion. Green investment, which refers to environmentally-friendly investment such as renewable energy, energy efficiency and sustainable agriculture, has been viewed as an important tool to promote sustainable development by striking a balance between economic progress and environmental protection. Nevertheless, literature that have established the relationship between green investment and economic growth in SSA are few in empirical studies. The heavy reliance of the region on non-renewable sources of energy. Even though there have been some policies trying to encourage green investments, how these investments affect economic growth over time is still not well understood. Because of this, the goal of this study is to look at how green investments influence economic growth in Sub-Saharan Africa, and to provide useful information that can help policymakers speed up the growth of green investments in the region [7].

This study is divided into five parts. The first part is an introduction that covers the background of the study, the problem being addressed, the goals of the research, and how the rest of the study is organized [8]. The second part is a literature review, which includes clear definitions of key concepts, existing research, areas that still need more study, and the main theories used in the research. The third part is about the methodology, which explains where the data comes from, how the variables are measured, the model used, and what the researcher expects to find. The fourth part presents the results of the study and discusses them in detail. The last part is the conclusion and recommendations, which summarizes the main findings, draws final conclusions, and suggests practical steps or policies that could be implemented based on the research.

2. Literature Review

2.1 Green Investment

Green investment means putting money or resources into projects or companies that focus on being eco-friendly, using technologies that are good for the environment, and making smarter use of natural resources. This helps improve both the environment and the economy, benefiting society as a whole. Green investment involves supporting clean energy, which comes from sources that don’t pollute the air. Clean energy, also called green energy, is produced from natural sources. In simple terms, green investment is a way of investing that supports businesses and projects that take care of the environment and help preserve natural resources [9].

2.2 Economic Growth

Economic growth happens because of how different macroeconomic factors relate to each other. It depends a lot on how much a country saves after accounting for its needs, and it's affected by how much capital is needed to produce each unit of output. Economic growth means that the amount of goods and services produced per person or per worker goes up. This often happens when output increases, which can also be because the population is growing. The idea of economic growth is about having a steady rise in the average income per person over time. It's measured by looking at income per person divided by the total number of people. Economic growth also means the economy becomes better at making more goods and services over time compared to before. This can be measured either with numbers that include inflation or without inflation [10].

2.3 Theoretical Review

2.3.1 Environmental Kuznets Curve (EKC) Theory

Environmental Kuznets Curve theory was named after American economist and statistician Simon Smith Kuznets in the 1970s. The theory talks about how economic development connects with income inequality. It says that as an economy grows, income inequality first goes up and then comes down. However, the Environmental Kuznets Curve looks at how environmental quality relates to economic development. Many signs of environmental damage get worse as the economy grows, but once average income reaches a certain level, these negative effects start to improve. The curve suggests that environmental problems can get better with economic growth.

Moreover, when the environmental Kuznets curve (EKC) theory is used to look at different environmental quality measures like air and water pollution, and the ecological footprint, it shows an upside-down U shape [11]. As the economy grows and the Gross Domestic Product per person goes up, pollution first increases but then starts to decrease after a certain point. In the case of deforestation, poorer countries face serious problems with losing forests, while richer countries can keep their forests and green areas even as they grow economically quickly through high consumption and exports, which helps them develop in a sustainable way. This theory helps understand both developed and developing countries, showing that environmental pollution, especially from direct emissions into air and water, has strong connections to economic issues and health problems like inflation and public health crises such as diseases and deaths [12]. Therefore, continuous economic growth, along with changes in regulations and technology, including research and development, using renewable energy, and better environmental policies, can lead to a more eco-friendly future with lower carbon emissions and sustainable development.

Thus, the KEC approved intuition in terms of an inverse relationships between economic and environmental pollution in the long run but the theory was associated with the lack of knowledge about the of the certain types of pollution, threshold effect. Also, the pollution is not simply a function of income, but it depends on many factors such as effectiveness of environmental regulation, global warming, literacy rate and population level.

2.3.2 Endogenous Growth Theory

Endogenous growth theory was introduced by Romer in 1987. This theory shows that changes in the saving rate can affect the economy's growth rate in the short term, but it does not influence the long-term growth rate. In contrast, neoclassical growth theory suggests that countries with different saving rates but similar population growth rates will eventually grow at the same rate and reach the same level of income per person in the long run. This idea led to the development of the new growth theory, which was created because the neoclassical model had some weaknesses. The neoclassical model assumed that technological change was an external factor, not influenced by the economy itself. The new growth theory argues that technological progress comes from within the economy and can be influenced by policies and investments, leading to sustained economic growth. This theory also suggests that sharing technology between countries can lead to more balanced economic growth over time [13].

Moreover, the neoclassical growth model couldn't explain why some countries grow faster than others. So, the main idea of endogenous growth theory is to understand why countries have different growth rates and to figure out how each factor contributes to economic growth. The new growth theory builds on the neoclassical model by making both technological progress and population growth factors that come from within the system. This theory looks closely at where growth really comes from and has three main ways of treating technological progress as an internal factor that affects economic growth. The first of these is including technological change, and the production function model was changed to reflect this:

$$Yt = f(Kt, Nt, At) \quad (1)$$

Where Y is output, the quantity of capital (K), labour (L), and technology (A) are factor inputs. While F is the functional relationship, and the subscript t is the period. Thus, using technology as endogenous factor input in the model, the relationship between output and technology is different not the same as between output and other inputs (capital and labour) because the output of an individual depends on its stocks of labour and capital but on the technology utilized by other firms or the countries would yield more benefits as an increase in output [14]. In the second approach, the new growth theory stated the Constance return to scale due to an external increase return to scale as the result of technological improvements from the rate of investment, size of capital stock, and stock of human capital. However, in the second approach technological progress was incorporated into the neoclassical growth model to yield a steady state in equilibrium as shown in the equation below:

$$Sf(k^*) = (a + bs + n)k \quad (2)$$

When people save more and invest more, the economy grows faster. This also means that different regions or countries may grow at similar rates over time. The theory says that investment helps create new technologies, which lead to innovations. As companies try to solve problems, they come up with new ways to make work more efficient. If some companies succeed, others will copy those ideas and adapt them to fit their own situations. This kind of technological progress is known as "Learning by Watching.".

Even though there are outside factors, learning by observing plays a key role in economic growth. Quick overall growth can happen if we create policies that encourage more spending on research and development. The endogenous growth theory helps explain how economic growth and innovation can speed up over time, especially through investing in people's skills and learning from experience. According to Luca's (1990) new growth model, the more workers there are, the more they can learn and gain new skills and knowledge. Gaining these new skills and technologies makes workers more efficient, and also boosts the efficiency of capital and other workers in the economy, as shown in the model that looks at the effects of human capital and productivity:

$$Y = Ak^{\alpha}(HeL)^{1-\alpha} \quad (3)$$

Technological progress affects human capital, which in turn influences how productive capital and labor are. Investing in human capital helps make all the resources used in production more efficient. New growth theory suggests that for a country to grow quickly or catch up with others, it needs to invest more in human capital and research and development. Governments can help the economy grow by directly or indirectly supporting the development of human capital and by encouraging foreign investments in industries that rely on knowledge. This helps create long-term development. However, the model based on human capital and economic growth doesn't fully consider other important factors that are needed for growth, like environmental protection, political stability, and the quality of institutions [15].

2.3.3 Green Growth Theory

The green growth theory/model was propounded by the Organization for Economic Corporation Development (OECD), 2011. The theory focus on the technological advancements for the mitigations of environmental challenges of 21st century for sustainable development through migration from the consumptions of nonrenewable to renewable energies accompanied by technological advancement. The growth model was adapted from the Solow-Swan growth model, incorporating environmental capital and pollution dynamics.

$$Y_t = f(L_t + K_t P_t + E_t + A_t) \quad (4)$$

Where, Y=Output, K= physical Capital, A= Technological Progress (green technology), E= Environmental quality or natural capital and P= Pollution emission.

Therefore, the pollution equation are;

$$\frac{dP_{(t)}}{d_t} = \varnothing \, . \, Y_t - \theta \, . \, A_{(t)} \quad (5)$$

$\varnothing$ = Pollution intensity of output, θ = Effectiveness of green technology in reducing pollution.

Environmental capital Dynamic are;

$$\frac{dE_{(t)}}{d_t} = \delta - \gamma . \, P_{(t)} \quad (6)$$

The growth depend on the capital accumulation, labour and environmental quality. The innovation and investment in green technology reduce pollution and improve environmental efficiency. If is sufficiently larger, than growth can be decoupled from environmental degradation achieving green growth. Absolutely, the green growth theory and model provides a framework to achieve economic development with environmental stewardship through integrating environmental capital and pollution into mainstream growth model. Also, it emphasizes the role of innovation, efficient resource use and institutional policies in ensuring sustainable long-term growth [16].

2.4 Empirical Literature

Nguyen (2024) looked at how green investment affected Russia's green economic growth from 2010 to 2021. They used yearly data and a method called Two-Stage Regression Analysis. The study showed that green investment helps green economic growth directly and also helps by lowering environmental pollution. They also noticed that green investment, CO2 emissions, and green economic growth influence each other, which means working together across different parts of Russia is important for progress in green development [17]. The results suggest that the government should create a development plan, because their actions can influence nearby areas. The Russian government needs to make a clear plan to move towards a green economy. This can be done through policies like taxes and subsidies for green businesses and projects, and by encouraging banks and financial institutions to support green financial tools.

Raihan et al. (2024) looked at how renewable energy, trade openness, economic growth, and carbon emissions are connected in India. They used data from 1965 to 2022 and a method called the Autoregressive Distributive Lag (ARDL) approach. Their study found that agricultural productivity and trade openness lead to more CO2 emissions, but economic growth helps to reduce CO2 emissions during this time. The researchers suggest that the government should look at environmental policies and trade changes to lower carbon emissions and encourage green investments [18].

Kwilinski et al. (2023) studied the effect of greenfield investments on green economic growth in the European Union (EU) from 2006 to 2020. They used the Malmquist-Luenberger Global Productivity Index to measure green economic growth. Their research showed that uneven technological efficiency and progress can stop green innovations from working well. However, green investments, economic openness, and good public governance have a positive effect on green economic growth in EU countries. The study recommends that the EU should increase spending on digitalizing government activities and green foreign direct investment to support sustainable development.

Shahzadi et al. (2023) looked at how economic growth and renewable energy affect environmental quality in the Regional Comprehensive Economic Partnership (RCEP). They used data from 12 countries between 1990 and 2020. They applied Non-linear Panel Regression and Fully Modified Least Squares (FMLS) methods [19]. Their results showed that financial development, economic growth, and renewable energy all help in reducing carbon emissions. All the factors studied had a positive effect on the environmental sustainability of these countries. The study suggests that the Spanish government should promote investment in environmental technology research and development to lower carbon emissions and support sustainable development.

Thai et al. (2023) studied the effect of natural resource extraction and green energy on economic growth in Asian countries from 2006 to 2020. They used Quantile Regression Analysis and the Ordinary Least Squares Fixed Effects method. Their findings showed that natural resource rents lead to higher carbon emissions, while renewable energy use lowers emissions and improves environmental quality. The study highlights the need to shift towards green energy to reduce the environmental damage caused by natural resource extraction. The results also suggest that implementing energy reservation policies can help improve both economic growth and environmental quality in these countries.

Shang (2023) examined the link between environmental technologies, green investment, and economic growth in China using time-series data from 1975 to 2020 and the Nonlinear ARDL (NARDL) method. Their results showed that in the short term, environmental technologies, industrialization, positive shocks from natural resource depletion, and negative shocks from renewable energy use and technological progress affect carbon emissions. In the long term, positive shocks from environmental technologies and economic growth, along with negative shocks from consumption and technical innovation, influence carbon emissions. The study suggests that investing in environmental technology, financial development, technological innovation, and renewable energy should help the Chinese government achieve sustainable prosperity.

Moslehpour et al. (2023) looked at how environmental concern, knowledge about the environment, green products, and eco-innovation affect people's intentions to buy green products in Taiwan's industry. They used data collected at a single point in time from customers and applied the Partial Least Squares method. Their results showed that customer attention plays a key role as an intermediary factor. It helps strengthen the connection between environmental knowledge, environmental concern, green products, and eco-innovation, which in turn boosts the desire to buy green products. The study suggests that the government should focus more on improving information and communication technology and on educational programs to raise awareness about the effects of green investments and environmental issues [20].

Hordofa et al. (2023) looked into whether eco-innovation and green investment help reduce CO2 emissions in China. They used data from 1990 to 2019 and applied the Autoregressive Distributed Lag (ARDL) model. They used environment-related technologies and patents as measures of eco-innovation. Their results showed that both eco-innovation and green investment have a negative effect on CO2 emissions, meaning they help lower environmental damage. The study suggests that governments should create policies that support the environment and make more investments in green initiatives.

Saqib et al. (2023) studied how green technological innovation, economic complexity, energy productivity, renewable electricity generation, and environmental taxes affect CO2 emissions in G-10 countries from 1995 to 2020. They used advanced panel analysis methods. Their findings found that using more environment-based technology, greater economic complexity, and higher levels of renewable electricity significantly cut carbon emissions in both the short and long term. The study advises governments to promote modern tax systems, improve tax collection, and offer regulations that help individuals support sustainable development goals [21].

Fan et al. (2023) looked into how green investment, economic growth, and environmental taxes are connected in six Asian countries (ASIAN-6) between 1995 and 2018. They used advanced statistical methods that accounted for cross-sectional dependencies and differences in slopes. Their results showed that green energy and green investment help drive green technology innovation in both the short and long term. The study also found that environmental taxes and green investment have a positive effect on economic growth. Based on these findings, the authors suggest that governments should create policies that reduce carbon emissions and lower production costs to support long-term economic sustainability [22].

Dzwigol et al. (2023) studied how environmental regulations, renewable energy, and energy efficiency affect green economic growth in EU countries from 2000 to 2020. They used the Global Malmquist-Luenberger Productivity Index to analyze the impact. The study found that the effect of environmental regulations on green growth follows a U-shaped, nonlinear pattern. Green investment and efficient use of renewable energy were also found to have a strong positive impact on green growth. The authors recommend implementing strong environmental regulation policies to promote carbon-free development in European countries.

Zang and their team in 2023 looked at how green energy use and technological progress affected sustainable development in Spain from 1980 to 2018. They used a model called NARDL to analyze the data. Their results showed that when there was an increase in renewable energy use and technological innovation, the environment improved and carbon emissions went down. The study suggested that the Spanish government should invest more in research and development for environmental technologies to make sustainability better and emissions lower [23].

Kwilinski and their group in 2023 studied how Greenfield investments impacted green economic growth across the European Union between 2006 and 2020. They used panel data and a tool called the Malmquist-Luenberger Global Productivity Index to measure green growth, taking into account factors like labor, capital, and energy as inputs, and GDP and environmental emissions as outputs. They used the Tobit model to test their ideas, and found that green economic growth varied a lot between EU countries. While green investments, open economies, and good public management helped green growth, differences in technology efficiency and progress slowed the impact of green innovations. The study suggests that strong environmental regulations should be put in place to support carbon-free development in Europe.

Abdul and their team in 2023 looked into how energy efficiency, the green economy, and technological innovation are connected in OECD countries from 1990 to 2020. They used tests like cross-sectional dependency tests, the Westerlund test, and quantile regression analysis. Their findings showed that using more renewable energy and advancing technology helps grow the green economy [24]. They also found that strong governance is important for encouraging eco-friendly production methods. Based on their results, they suggested that organizations should create energy policies to reduce environmental damage.

Zeraibi and their group in 2023 studied the link between greenfield investment, economic complexity, financial inclusion, and environmental quality in BRICS countries from 2003 to 2018. They used the Pooled Mean Group (PMG) method. Their results showed that urbanization, greenfield investment, and economic complexity all help move toward using more renewable energy. They recommended that industrial sectors in BRICS nations should focus on clean and renewable energy to speed up green economic growth [25].

Sheng (2023) looked at how green investment, economic innovation, and financial inclusion contribute to sustainable development in China between 1991 and 2020. They used a Bayesian Autoregressive Distributed Lag (BARDL) model and found that green investment, eco-innovation, financial inclusion, and research and development (R&D) spending all have a positive effect on sustainable development, as measured by the Human Development Index (HDI). The study suggested that more investment in green energy and R&D could help further support sustainable development.

Erdogan et al. (2023) studied the different effects of renewable and nonrenewable energy use on carbon emissions in Canada from 1965 to 2017. Using Nonlinear ARDL and Vector Autoregression (VAR) models, they found that increases in renewable energy use lead to lower carbon emissions. However, economic growth and nonrenewable energy use have uneven effects, increasing emissions in certain ways. The study emphasized that boosting renewable energy use is key to cutting carbon emissions and supporting both environmental and economic sustainability.

Ben et al. (2023) looked at how green investment, moving to low-carbon energy, and economic growth affect environmental quality in Asian countries between 2000 and 2021. They used the Generalized Method of Moments (GMM) to analyze the data. Their results showed that low-carbon emissions have a positive effect on environmental quality. Additionally, green investment and technology were found to help both economic growth and environmental improvements. The study suggests that increasing the use of low-carbon and renewable energy can lead to better environmental results.

Zheng and Ji (2023) studied the effect of green investment on corporate sustainability in China from 2010 to 2020. They used Fixed-Effect Regression Analysis and found that green investment helps improve corporate sustainability. Factors that influenced this effect included government support, how much companies focused on sustainability, and green foreign investments. These factors helped reduce the negative impact of carbon emissions on businesses. The study recommends that governments and industries should adopt green management strategies to boost sustainability in the industrial sector [26].

Adegoriola et al. (2020) looked at how energy is used and how much carbon is emitted in Nigeria between 1990 and 2019. They considered factors like carbon emissions, oil use, gas fuel use, and overall fossil fuel consumption. Using the Kuznets Environmental Hypothesis, Johansen cointegration, and Vector Error Correction methods, their study found that higher energy use leads to more carbon emissions. They also found that the Kuznets hypothesis works well for understanding environmental pollution connected to energy use in Nigeria. Based on these results, the government is advised to create strong policies that can help reduce carbon emissions and support environmental sustainability.

Research on green investment shows there are still many unanswered questions in Sub-Saharan Africa (SSA). Even though there are useful studies in places like Russia, China, and India, there is not enough focused research on SSA. This region has its own special economic and social problems, including high levels of poverty, unemployment, and environmental damage. More studies that are specific to SSA are needed to see how green investments can help both the economy and the environment. Even though the long-term benefits of green investment for economic growth have been studied in other areas, this hasn't been well explored in SSA. This is because many countries in the region depend heavily on non-renewable resources, making it hard to assess the potential of green investments. Also, the effects of green investment on regional cooperation and integration are not well understood. Some SSA countries have started policies to support green investment, but it's unclear how effective these policies are in helping sustainable development. Since there are few similar studies in SSA, this research is important for understanding how green investments can help the region grow economically in a sustainable way [27].

3. Methodology

3.1 Nature and Source of Data

This study used annual panel data covering 1990 to 2023 for 12 Sub-Saharan African (SSA), four countries from 3 regions. The selected countries are as follows: Eastern Africa: Kenya, Malawi, Mozambique, and Zimbabwe. Central Africa: Angola, Equatorial Guinea, DR Congo, and Sao Tome and Principe. Southern Africa: Botswana, Lesotho, Namibia, and South Africa. Western Africa: Mauritania, Côte d'Ivoire, Nigeria, and Sierra Leone. The data for all variables included in the model will be sourced from the World Bank (2023). The variables to be used are: Green Investment (GIN) Carbon Emissions (CO2), Economic Growth (measured by DGDP), Gross Capital Formation (GCF), Labor Force (LBF), and Foreign Direct Investment (FDI). These variables were selected to establish the link between green investment and economic growth in Sub-Saharan Africa.

Table 1. Description, Measurement and Source of Data

Variable	Description of Variables	Measurements	Source
Green Investment (GIN)	Clean is noncarbohydrate energy that does not produce carbon dioxide when generated. It includes hydropower and nuclear, geothermal, and solar power, among others.	Millions USD ($).	World Bank (2024)
Economic Growth (DGDP)	The Difference of Per Capita values for Gross Product (DGDP).	Thousand USD ($)	W.B. (2024)
Gross Capital Formation (GCF)	Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories.	Percentage of GDP.	W.B. (2024)
Labour Force (LBF)	Labour force refers to the productive ages that are available for work and seeking employment.	% of the working age population.	W.B. (2024)
Foreign Direct Investment (FDI)	Foreign direct investment is the net inflow of foreign investment in an enterprise operating in an economy.	Millions USD ($).	W.B. (2024)
Emission (CO_2)	CO_2 emissions from electricity and heat production are the sum of CO_2 emissions.	Metric Tons	W.B. (2024)

Source: Author's Design, 2025

Table 1 explains the variable definitions, measurement methods, and data sources used in your research. For example, if your research explores the impact of green investment on economic growth, then GDP, green investment, CO_2 emissions, and FDI are core variables the model.

3.2 Models Specification

This study used triangulation approach anchored on Romer (1987) new endogenous growth model and Kuznet (1970) environmental kuznet curve theory that explained the determinants of national output through macroeconomic endogenous variables (technology and green investment) as shown in equation (4) and (5)

$$Y_t = f(K_t, N_t, A_t) \quad (7)$$

Where Y represent output, and K(capital), L (labor), and A (technology) serve as factor inputs, f denotes the functional relationship, while the subscript t indicates the time period. By treating technology as an endogenous factor input within the model, the relationship between output and technology differs from that with other inputs, such as capital and labor. This is because an individual's output depends not only on its own stocks of labor and capital but also on the technology employed by other firms or countries. Such external technology can generate additional benefits, leading to increased output. The Equation (4) has been modified by inclusion of green investment, carbon emissions and foreign direct investment as environmental endogenous variables to enhance the robustness of the relationship between green investment and economic growth.

$$DGDP = f(CO_2, FDI, GCF, GIN, LBF) \quad (8)$$

Where; DGDP= Economic Growth, FDI= Foreign Direct Investment, CO_2= Carbon Emission, GCF= Gross Capital Formation, GIN= Green Investment and, LBF= Labour Force.

Equation (3) is therefore linearized model

$$DGDP_{it} = \beta_0 + \beta_1 Co2_{i,t} + \beta_2 FDI_{it} + \beta_3 GCF_{it} + \beta_4 GIN_{it} + \beta_5 LBF_{it} + \varepsilon_{it} \quad (9)$$

Where; β_0 is an intercept while, β_1, β_2, β_3,…..β_n are vectors of independent consonants then ε is the vector of stochastic variables and *it* are panel time series.

The study assumes that the coefficient of carbon emissions has a negative effect on economic growth. In contrast, the coefficients of foreign direct investment, gross capital formation, green investment, and the labor force will positively affect the economic growth of the selected Sub-Saharan African countries.

3.3 Panel Unit Root Tests

In any time, series estimation analysis, ensuring the stationarity of variables is crucial to avoid spurious regression results. A panel unit root test will be conducted to determine whether the series are stationary at levels or require differencing, serving as a guide for selecting the appropriate technique for empirical analysis. Accordingly, this study employs the second-generation unit root tests proposed by Pesaran (2015, 2021), Juodis and Reese (2021), and Pesaran and Xie (2021) to investigate the presence of a unit root in a cross-sectionally dependent panel data set. The proposed test statistic is formulated as follows:

$$\Delta y_{it} = \alpha + p y_{it-1} + \theta_1 \Delta y_{it-1} ... + \theta_k \Delta y_{it-k} + \mu_{it} \quad (10)$$

$$CSD(N,T) = N^{-1} \sum_{i=1}^{N} ti(N,T) \quad (11)$$

Where ti (*N*,*T*) is the cross-sectionally augmented Dickey–Fuller statistic for the *i*th cross section unit.

3.3.1 Panel Autoregressive Distributive Lag (ARDL)

The Autoregressive Distributive Lag (ARDL) of this study generated from the equation (6) generic model specified by Peseran *et al,* (2011) to analyze the long-run relationships between the economic growth and some factors as independent variables as was clearly captured in equations (2) and (3) above respectively.

$$GDP_{it} = \alpha_{it} + \sum_{j=1}^{p} \lambda_{ij} GDP_{i,t-j} + \sum_{j=0}^{\alpha} \delta_{ij} \beta_{i+t-j} + v_{it} \quad (12)$$

Where; λ_{ij} is the coefficient of the dependent variable lagged by the specific period which can also be the determinant factor of concurrent economic growth is the vector of regressors lagged by the specific period and δ_{ij} is the coefficient of the vector.

The study anticipates that the parameters of major independent variables green Investment (GIN) and economic growth (DGDP) will have a long-run effects on economic growth in SSA. Also, an expectation of long-run effect in equation (13) leads this study to specify the error correction model to analyze the speed of convergent for economic growth from long-run to short-run equilibrium.

3.3.2 Panel Error Correction Model (ECM)

The error correction model for this study drive from the generic panel ARDL model of equation (9) to analyze the speed of disequilibrium from long-run to short-run for economic growth in SSA.

$$\begin{aligned} &\Delta DGDP_{it} + C_{i,1} + \alpha_{i,1} DGDP_{it-1} + \alpha_{i,2} \Delta DGDP_{it-2} .....+ \alpha_{i,p} \Delta DGDP_{i,t-p} \lambda_{i,0} \Delta \beta_{i,t} .....+ \\ &\lambda_{i,1} \Delta \beta_{i,t-1} + \lambda_{i,p} \Delta \beta_{i,t-p} + \alpha_i (DGDP_{i,t-1} - \lambda_i \beta_{it-1}) + v_{i,t} \end{aligned} \quad (13)$$

Where the change in economic growth is, is an intercept, is the coefficient of lagged economic growth as an independent consonant or determinant of the concurrent economic growth. $\lambda_{i,0}$, and are coefficients of the vectors of the lagged independent variables then $\Delta\beta_{i,t}$, and are vector changes of lagged independent variables over the period of the study.

3.3.3 Panel Granger Causality Model

The panel granger causality test will be employed to investigate the causative relationships between the variables, and it will present in equations (14) to (15) respectively below:

$$\Delta GIN_{,it} = \varnothing_{1,j} + \sum_{k} \varnothing_{11,ik} \Delta GIN_{,it-k} + \sum_{k} \varnothing_{12,ik} \Delta DGDP_{it-k} + \mu_{1,it} \quad (14)$$

$$\Delta DGDP_{it} = \varnothing_{2,j} + \sum_{k} \varnothing_{21,ik} \Delta DGDP_{,it-k} + \sum_{k} \varnothing_{22,ik} GIN_{it-k} + \mu_{2,it} \quad (15)$$

The null hypothesis of the Granger causality test is that the lagged of the explanatory variable does not justify the variation in the dependent variable. Therefore, $H_0 : \varnothing_{12ik} = 0$ or $H_0 : \varnothing_{21ik} = 0$. If the null hypothesis is rejected GIN granger cause DGDP and vice-versa.

4. Results and Discussion

Table 2. Descriptive Statistics

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
DGDP	408	2577	2463.	280.3	14222
CO_2	408	1.551	2.017	.0300	8.447
GIN	408	53.44	26.90	3.680	98.34
GCF	408	1.271	2.008	4.961	8.312
FDI	408	8.208	2.768	-7.397	4.130
LBF	408	85756	14390	36752	70620
NOTE: GDP= Economic Growth, CO_2=Carbon Emission, GIN=Green Investment, GCF=Gross Capital Formation, FDI= Foreign Direct Investment.					

Source: Author's Computations Using Stata 17 version, 2025

Table 2 presents the summary statistics of the series. The mean economic growth of the 12 selected SSA countries was 2,577 with a standard deviation of 2,463.7. The minimum value was 280.3, and the maximum value was 14,222 over the study period. For carbon emissions (CO_2), the mean value was 1.55 metric tons, with a standard deviation of 2.02. The minimum emission was 0.03 metric tons, while the maximum emission per annum was 8.45 metric tons. Regarding investments in zero-emission energy, referred to as green investment, the mean was 53.44 million USD, with a standard deviation of 26.91 million USD. The minimum green energy investment was 3.68 million USD, while the maximum was 98.34 million USD per annum over the study period. The summary statistics for gross capital formation (GCF) in SSA show a mean of 1.27 million USD, with a standard deviation of 2.00 million USD. The minimum value was 4,961.58 thousand USD, and the maximum was 8.31 million USD over the period of the study.

Also, for the foreign direct investment (FDI) inflow, the mean (average) was 8.21 million USD, with a standard deviation of 2.77. The minimum FDI was -7.34 million USD, indicating a reduction in revenue generated from FDI inflow by 7.34 million USD per annum, possibly due to institutional changes during the study period. Lastly, the summary statistics for the labor force (LBF) reveal an average working population of 8,576 people, with a standard deviation of 1,439 per annum. The minimum working-class population was 36,752 thousand people, and the maximum was 70,620 people, contributing to economic growth through green investment in SSA over the study period.

Table 3. Panel Unit Root Test Result

	CD	CDw	CDw+	CD*
DGDP	24.530	-1.480	268.460	1.730
	(0.000)	(0.140)	(0.000)	(0.083)
CO2	9.120	-3.750	212.380	0.160
	(0.000)	(0.000)	(0.000)	(0.875)
GIN	24.750	-2.270	267.780	4.730
	(0.000)	(0.023)	(0.000)	(0.000)
LBF	45.300	1.700	369.740	-3.350
	(0.000)	(0.090)	(0.000)	(0.001)
FDI	10.640	-0.020	114.760	3.520
	(0.000)	(0.987)	(0.000)	(0.000)
GCF	22.200	-2.360	199.330	3.900
	(0.000)	(0.018)	(0.000)	(0.000)

p-values in parenthesis. References CD: Pesaran (2015, 2021) CDw: Juodis, Reese (2021) CD*: Pesaran, Xie (2021)

NOTE: GDP= Economic Growth, CO_2=Carbon Emission, GIN=Green Investment, GCF=Gross Capital Formation, FDI= Foreign Direct Investment.

Source: Author's Computations Using Stata 17 version, 2025

Table 3 presents the results of the second-generation panel unit root test and the cross-sectional dependency analysis of the series in the model. This study employed three different unit root and cross-sectional dependency tests to ensure conformity of stationarity and the spillover effect of the series in SSA during the study period (Pesaran, 2015, 2021; Juodis et al., 2021; and Pesaran et al., 2021). The results indicate that all the variables are stationary at level and exhibit spillover effects in SSA, as shown in the CD and CDw+ tests (Pesaran, 2015, 2021; Juodis & Recee, (2021). However, the CDw outcomes reveal that only carbon emissions (CO_2), green investment (GIN), and gross capital formation (GCF) have spillover effects. In contrast, economic growth (DGDP), labor force (LBF), and foreign direct investment (FDI) do not exhibit cross-sectional dependency across SSA, as indicated by the CDw test. Similarly, according to Pesaran (2021), all variables except economic growth and carbon emissions demonstrate spillover effects. The mixed outcomes derived from employing different stationarity and cross-sectional dependency tests justify the adoption of the panel autoregressive distributed lag (Panel ARDL) model in this study.

Table 4. Westerlund Panel Cointegration Test Result

Hypothesis: H_0: no cointegration

Statistic	Value	Z-value	P-value
Gt	-3.472	-1.721	0.043
Ga	-7.840	4.293	1.000
Pt	-5.003	4.666	1.000
Pa	-2.755	4.963	1.000

Source: Author's Computations Using Stata 17 version, 2025

Table 4 presents the panel cointegration test results. Based on the outcomes of the unit root tests in Table 3, the presence of a unit root in some variables within the model was confirmed. Therefore, it became necessary to investigate the long-run relationship among the variables. To this end, the study employed the Westerlund panel cointegration test. The results revealed the presence of cointegration between economic growth and green investment, supported by the evidence of the GtG_tGt statistic (-3.472 & p-value = 0.043), which is statistically significant at the 5% level, indicating rejection of the null hypothesis. These findings align with the empirical results of Sharf et al. (2023), Yunquian et al. (2023), and Saqib et al. (2022). The presence of cointegration provides an opportunity to further investigate the long-run and short-run relationships, as well as the speed of convergence (disequilibrium) from long-run to short-run equilibrium in SSA during the study period.

Table 5. Panel ARDL Short Run and Long Run Results for Green investment and Economic Growth

Dependent Variable: DGDP	Coefficient	Standard Error.	Z	P>z	[95% Conf.	Interval]
Short Run Est.						
Mean Group:						
GIN	-17.556	7.137	-2.460	0.014	-31.544	-3.567
GCF	0.002	0.002	1.000	0.317	-0.002	0.005
CO2	168.16	186.74	0.900	0.368	-534.17	197.84
FDI	-0.000	0.000	-0.300	0.764	-0.000	0.000
LBF	0.001	0.002	0.300	0.765	-0.003	0.004
L.DGDP	-0.607	0.075	-8.050	0.000	-0.754	-0.459
Adjust. Term						
Mean Group:						
lr_GDP	-1.607					
Long Run Est.						
Mean Group:						
lr_CO2	-01.108	118.48	-0.850	0.393	-333.33	131.12
lr_FDI	-0.000	0.000	-0.500	0.620	-0.000	0.000
lr_GCF	0.001	0.001	1.000	0.317	-0.001	0.003
lr_GIN	10.411	4.643	2.240	0.025	-19.512	1.310
lr_LBF	0.000	0.001	0.170	0.863	-0.002	0.003

Note: GDP= Economic Growth, CO_2=Carbon Emission, GIN=Green Investment, GCF=Gross Capital Formation, FDI= Foreign Direct Investment.

Source: Author's Computations Using Stata 17 version, 2025

Table 5 presents the panel short-run and long-run results of economic growth and green investment, along with some independent variables that determine economic growth in SSA. In the short run, the results show that green investment has an inverse relationship with economic growth, evidenced by a coefficient of -17.6 and a p-value of 0.0014, which is statistically significant at the 5% level. This implies that, during the initial stages of adopting or consuming green energy, the costs of installing and maintaining zero-emission systems negatively impact the economic growth of SSA, leading to a decrease of approximately 17.6 million USD. In the long run, however, green investment has a positive effect on economic growth, with a coefficient of 10.41 and a p-value of 0.025, which is also statistically significant at the 5% level. This indicates that, in the long term, a 1 million USD increase in green investment would boost the economic growth of SSA by approximately 10.41 million USD per annum. This improvement is attributed to a reduction in production costs and increased working hours per laborer due to improved electricity stability. These findings align with empirical studies.

Furthermore, gross capital formation (GCF) has a positive effect on economic growth (DGDP), with a coefficient of 0.002. This indicates that higher marginal efficiency of capital leads to more investments, which subsequently enhance economic performance [28]. This finding aligns with Nurkse's (1971) assumption regarding the vicious cycle of poverty, emphasizing that increased capital formation is a key factor in breaking the poverty cycle in developing countries. Carbon emissions (CO_2) have a positive effect on economic growth in the short run, with a coefficient of 168.17. This means that for every additional metric ton of carbon emissions, economic growth improves by approximately 168.17 thousand USD. However, in the long run, carbon emissions have a negative effect on economic growth, as indicated by a coefficient of -101.12. This suggests that a 1 metric ton increase in carbon emissions may lead to a decrease of approximately 101.12 thousand USD in economic growth per annum. These findings align with the Kwilinshiki et al. (2023) and Yiandom et al. (2023) which posits that in the early stages of economic development, emissions positively affect economic growth, but they reach a turning point where emissions have a negative impact in the long run.

The results also reveal that labor force (LBF) positively affects economic growth in both the short and long runs. In contrast, foreign direct investment (FDI) has a negative effect on economic growth in both the short and long runs, potentially due to economic and political instability in SSA during the study period. Finally, the results in Table 4 reference the findings in Table 2, which established evidence of cointegration among the variables. The adjustment term, captured by the mean group (MG) model with lrDGDP = −1.6 (p-value = 0.00), indicates a tendency for convergence or adjustment from the long-run equilibrium to the short-run equilibrium for economic growth, green investment, and other independent variables included in the model.

Table 6. Dumitrescu and Hurlin Granger causality test result for Green Investment and Economic Growth

Null Hypothesis:	W-bar	Z-bar	Z-bar tilde
GIN does not Granger Cause DGDP	3.5083	6.1441 (0.0000)	5.2751 (0.0000)
DGDP does not Granger Cause GIN	3.1923	5.3701 (0.0000)	4.5911 (0.0000)

NOTE: GIN=Green Investment, GDP= Economic Growth

Source: Author’s Computations Using Stata 17 version, 2025

Table 6 presents the Dumitrescu and Hurlin panel pairwise Granger causality test results for green investment (GIN) and economic growth (DGDP) in 12 selected SSA countries. The results reveal a bidirectional causality between green investment and economic growth, evidenced by the statistical significance of both the Z-bar statistic (6.1441, p=0.0000p = 0.0000p=0.0000) and the Z-bar tilde statistic (5.2751, p=0.0000p = 0.0000p=0.0000) over the study period. These findings align with some empirical reviewed.

This indicates that any positive or negative change in green investment will have a corresponding impact on economic growth in SSA, and vice versa, during the study period. For instance, an increase in investment in clean energy (zero-emission sources) such as solar power will reduce production costs and enhance economic productivity [29]. Conversely, a decline in green investment would likely hinder economic growth. Similarly, changes in economic growth directly affect green energy investment in SSA. For example, an increase in economic growth leads to higher aggregate demand for labor, resulting in increased per capita income and improved accessibility to clean energy consumption.

5. Conclusion and Recommendations

This study paper empirically examines the effect of green investment on the economic growth of sub-Saharan African (SSA) countries from 1990 to 2023. The results reveal the presence of cointegration between economic growth and green investment, alongside other economic variables in the model. The ARDL results show that, in the short run, green investment has an inverse relationship with economic growth. Furthermore, the pairwise Granger causality results indicate a bidirectional relationship between economic growth and green investment in SSA. The findings suggest that as the economy grows, the demand for clean and zero-emission energy will rise, leading to more economic opportunities and innovation. Conversely, increased green investment will also drive economic growth [30]. Based on the findings, the study recommends the following policies and insights to enhance the economic growth of SSA through clean energy consumption and other macroeconomic variables:

i. Sub-Saharan African governments should formulate policies aimed at enhancing economic productivity and improving access to clean energy sources.

ii. SSA countries should establish a regional green energy consumption forum or conference to serve as a platform for promoting and protecting sustainable development initiatives within the region.

iii. Governments should implement strong and effective environmental protection policies for both the public and private sectors. These policies will promote the use of clean energy and reduce carbon emissions across SSA.

iv. Both public and private sectors should invest in green Research and Development (R&D) to achieve a sustainable growth.

v. Stakeholders like governmental and nongovernmental organization should intervene to promote education and training for green jobs for sustainable environment.

References

[1] Adegoriola, A. E., & Adolphus, A. J. (2020). Energy utilization and pollution in Nigeria: A Case of carbon emission. Lafia Journal of Economics and Management Sciences, 5(2), 1-12.

[2] Chudik, A., Pesaran, M.H., (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. Journal of Economics, 188 (2), 393– 420.

[3] Cui, L. (2022). How China is Going Green: Pollution controls, green investment and policy implications (Doctoral dissertation, University of Bath). 78-125.

[4] Dalgaard, T., Bienkowski, J. F., Bleeker, A., Dragosits, U., Drouet, J. L., Durand, P., ... & Cellier, P. (2021). Farm nitrogen balances in six European landscapes as an indicator for nitrogen losses and basis for improved management. Biogeosciences, 9(12), 5303-5321.

[5] Dogan, E., Hodžić, S., & Fatur Šikić, T. (2022). A way forward in reducing carbon emissions in environmentally friendly countries: the role of green growth and environmental taxes. Economic research-Ekonomska istraživanja, 35(1), 5879-5894.

[6] Dzwigol, H., Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2023). The role of environmental regulations, renewable energy, and energy efficiency in finding the path to green economic growth. Energies, 16(7), 3090.

[7] Economic Outlook. (2022). National institute economic review 261. 2e.

[8] Erdoğan, E., Serin Oktay, D., Manga, M., Bal, H., & Algan, N. (2024). Examining the effects of renewable energy and economic growth on carbon emission in Canada: evidence from the nonlinear ARDL approaches. Evaluation Review, 48(1), 63-89.

[9] Hordofa, T. T., Vu, H. M., Maneengam, A., Mughal, N., & Liying, S. (2023). Does eco- innovation and green investment limit the CO2 emissions in China? Economic research-Ekonomska istraživanja, 36(1), 634-649.

[10] International Monetary Fund. Fiscal Affairs Dept. (2023). Tonga: Technical Assistance Report- Climate Change Policy Assessment. International Monetary Fund.

[11] Juodis, A., & Reese, S. (2022). The incidental parameters problem in testing for remaining cross- section correlation. Journal of Business & Economic Statistics, 40(3), 1191-1203.

[12] Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2023). Greenfield Investment as a Catalyst of Green Economic Growth. Energies, 16(5), 2372.

[13] Kuznets, S. (1955) Economic Development and Income Inequality. American Economic Review, 49,1–28.

[14] Mo, Y., Ullah, S., & Ozturk, I. (2023). Green investment and its influence on green growth in high polluted Asian economies: Do financial markets and institutions matter?. Economic Research-Ekonomska Istraživanja, 36(2), 2140302.

[15] Mohammad, M. T., Luni, T., & Zaka, G. (2021). Renewable energy consumption and health outcomes: Evidence from global panel data analysis. Pakistan Journal of Commerce and Social Sciences (PJCSS), 15(1), 58-93.

[16] Moslehpour, M., Yin Chau, K., Du, L., Qiu, R., Lin, C. Y., & Batbayar, B. (2023). Predictors of green purchase intention toward eco-innovation and green products: Evidence from Taiwan. Economic research-Ekonomska istraživanja, 36(2).

[17] Muhammad, B., & Khan, M. K. (2021). Foreign Direct Investment Inflow, Economic Growth, Energy Consumption, Globalization, and Carbon Dioxide Emission around the World. Environmental Science and Pollution Research, 28(39), 55643-55654.

[18] Nguyen, D. H., & Khominich, I. P. (2024). Green investment and green economic development in Russia. Regional Statistics, 14(2). 45-68.

[19] Nguyen, T. T. H., Tu, Y. T., Diep, G. L., Tran, T. K., Tien, N. H., & Chien, F. (2023). Impact of natural resources extraction and energy consumption on the environmental sustainability in ASEAN countries. Resources Policy, 85, 103713.

[20] Nurkse, R. (1971). The theory of development and the idea of balanced growth. In Developing the underdeveloped countries. London: Palgrave Macmillan UK. PP. 115-128.

[21] Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. Econometric reviews, 34(6-10), 1089-1117.

[22] Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. Empirical economics, 60(1), 13-50.

[23] Pesaran, M. H., & Xie, Y. (2021). A bias-corrected CD test for error cross-sectional dependence in panel data models with latent factors. arXiv preprint arXiv:2109.00408.

[24] Pesaran, M.H., (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. Econometrica, 74 (4), 967–1012.

[25] Pesaran, M.H., Tosetti, E., (2011). Large panels with common factors and spatial correlation. Journal of Economics, 161 (2), 182–202.

[26] Pettinger, L. (2019). Work as production. In What's Wrong with Work? Policy Press. 27-48.

[27] Raihan, A., Tanchangya, T., Rahman, J., & Ridwan, M. (2024). The influence of agriculture, renewable energy, international trade, and economic growth on india's environmental sustainability. Journal of Environmental and Energy Economics, 37-53.
[28] Raihan, A., Tanchangya, T., Rahman, J., & Ridwan, M. (2024). The influence of agriculture, renewable energy, international trade, and economic growth on India's environmental sustainability. Journal of Environmental and Energy Economics, 37-53.
[29] Understanding the importance of sustainable ecological innovation in reducing carbon emissions: investigating the green energy demand, financial development, natural resource management, industrialization and urbanisation channels. Economic Research-Ekonomska istraživanja, 36(2). 275-308.
[30] Zheng, S., & Jin, S. (2023). Can enterprises in china achieve sustainable development through green investment? International Journal of Environmental Research and Public Health, 20(3), 1787.