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Article

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Exploring the Impact of Good Governance and Innovation on Export Earnings, Clean Energy, Remittances, and Zero Carbon Emissions in Sub-Saharan African Countries

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ABSTRACT

The research examines how to export earnings, remittances, good governance, clean energy, innovation, and carbon neutrality are interconnected in Sub-Saharan African countries from 2001 to 2020. By using panel data analysis methods, the study explores the connections between these factors to understand the factors influencing carbon neutrality and their impact on sustainable development in the region. The analysis indicates that export earnings, remittances, and clean energy positively correlate with achieving carbon neutrality. Export earnings drive economic growth and support investments in cleaner technologies and environmental sustainability. Remittances boost household incomes, enabling the adoption of cleaner energy sources. Additionally, using clean energy technologies is linked to lower carbon emissions, emphasizing the need to transition to renewable energy sources for carbon neutrality. Conversely, the findings suggest negative connections between good governance, innovation, and achieving carbon neutrality. Countries with stable governance tend to have lower carbon emissions due to the effective implementation of environmental policies. However, the negative link between innovation and carbon neutrality implies that technological progress can increase emissions without investments in clean energy and sustainable practices. The study also highlights the significance of good governance in enforcing environmental policies. Furthermore, it stresses the need to balance economic growth with environmental sustainability, emphasizing the role of innovation in achieving sustainable development. The study adds to current research by presenting data on the factors influencing carbon neutrality in Sub-Saharan Africa. It highlights the connections between export earnings, remittances, governance, innovation, clean energy, and carbon neutrality, offering vital information for policymakers aiming to encourage sustainable development and address climate change in the area.

Keywords: Export, Carbon Emission, Technological Innovation, Renewable Energy Consumption, SSA
JEL Classifications: Q55, Q42, Q50, Q58

1. INTRODUCTION

Emission of CO_2 will increase in economies where there is a weak lawful system to assure that contracts between government institutions and organizations or businesses do not include strict obedience to standards for a clean environment. The world has encountered challenges with environmental health due to carbon emissions for the past 130 years, as CO_2 emissions from vegetation, animals, and other similar bases have increased by 45% (Carbon Footprint Organization). According to the British Petroleum (BP) Statistical Review of World Energy, in 2017, carbon dioxide (CO_2) emissions were 33,444.00 million tons, which was an increase of 3729.8 million tons (1.6%) of emissions (British Petroleum Sarpong and Bein (2020). The report highlights statistics that suggest a need for more progress in worldwide efforts to combat climate change. Sub-Sahara African economies like Rwanda, Ghana, Kenya, and South Africa have shown progress in promoting good governance and innovation to support sustainable development. Good governance is critical in establishing a supportive environment for sustainable development. Nations that possess strong governance structures are better equipped to foster innovation Bekana (2020). The International Monetary Fund (IMF) emphasizes the significance of strong institutions that ensure honesty in overseeing public matters, as they are essential for achieving increased and more equitable economic growth Fund. The IMF's book, "Good Governance in Sub-Saharan Africa," features Botswana, Rwanda, and Seychelles as countries leading in the effort to improve governance Fund. According to the Mo Ibrahim Foundation Index of African Governance (IFAG), Rwanda has ranked among Africa's top five countries in governance performance since 2018. Ghana has seen considerable improvement in its governance scores, according to IFAG, ranking among the top ten African countries between 2017 and 2020. Kenya ranked third out of 54 countries in the 2021 Mo Ibrahim Foundation Index of African Governance. South Africa consistently ranks among the top three countries in Africa regarding governance performance, as per IFAG. Sub-Saharan Africa has seen considerable gains in digital government transformation, with countries like Kenya, Mauritius, Rwanda, Seychelles, and South Africa emerging as regional leaders Barasa (2022). Policymakers in sub-Saharan Africa utilize innovation and emerging technologies to improve governance and transparency. These advancements are essential for enhancing environmental quality by promoting renewable energy sources, energy-efficient practices, and eco-friendly technologies to reduce carbon emissions and promote Environmental Sustainability Fund (2022). The African continent is facing a significant environmental and public health crisis due to high levels of air pollution, particularly from CO_2 emissions. This pollution is causing over 770,000 deaths annually, with various sources like burning wood, agricultural residue, and industrial activities contributing to the problem Bauer et al. (2019). The impact is severe in the sub-Saharan region, affecting over 600,000 individuals and leading to health issues and loss of productivity. Industrialized economies account for more than 30% of worldwide energy usage and 20% of overall carbon dioxide emissions, leading to significant health hazards for the population. The African continent's industrial efforts raise concerns about potential environmental health risks Acar and Tekce (2014) and Cross (2015). Hence, the African continent faces challenges in maintaining environmental health as it works towards industrializing its economies.

The Sub-Saharan African region plays a significant role in pollution but needs solid environmental sustainability policies. Understanding the relationship between the environment and institutions in this region is crucial Abid (2016). Many countries have implemented environmental policies like the Kyoto Protocol to improve ecological health by promoting renewable energy sources. However, these efforts have yet to successfully reduce carbon dioxide emissions in Africa due to inadequate institutional structures that impede policy implementation Bekun et al. (2019a) and Bekun et al. (2019b). Transparency International reported that by the end of 2018, many African countries were perceived as highly corrupt, with a corruption index below 3. Notably, around 50% of the top ten most corrupt countries globally are from Africa Abid (2016). Due to widespread bribery and corruption, Africa faces a significant challenge in controlling CO_2 emissions. Ineffective regulatory frameworks and governance systems across the continent worsen this issue Appiah et al. (2022).

Achieving zero carbon emissions in Sub-Saharan African nations necessitates a comprehensive strategy that includes several essential components. These include diversifying energy sources by shifting from fossil fuels to renewable options like solar, wind, and hydropower and increasing investments in renewable energy infrastructure and technologies Ellabban et al. (2014). Implementing energy efficiency measures in various sectors, such as industries, transportation, and buildings, is crucial for reducing carbon emissions Tanaka (2011). Promoting good governance and transparency and combating corruption is vital for successful climate action and sustainable development Sukoharsono (2018). Strengthening financial systems to support green investments and adopting technological innovations in clean energy are also important Bose et al. (2019). Developing and enforcing climate policies, regulations, and incentives in Nigeria are vital in driving the adoption of clean energy and carbon reduction strategies, leading to significant progress in Sub-Saharan Africa's efforts to achieve zero carbon emissions. This holistic approach aligns with global initiatives to address climate change and advance sustainable development in the region Daggash and Mac Dowell (2021).

In our study, why should export earnings, remittances, good governance, and innovation be considered crucial factors in Sub-Saharan African nations' efforts to achieve carbon neutrality? Sub-Saharan African countries heavily depend on natural resources, especially fossil fuels, which comprise a large part of their GDP. However, these industries also contribute significantly to greenhouse gas emissions, creating a challenge in striving for carbon neutrality. Moving towards a low-carbon economy requires moving away from non-renewable energy exports, a significant challenge for economies abundant in such resources Gyimah et al. (2023). Investing in clean technologies using export earnings can promote the development and adoption of renewable energy sources, reducing dependence on carbon-intensive industries and working towards achieving zero carbon emissions Lu et al. (2023). Transitioning to a net-zero economy can significantly impact economic growth and job creation, as aligning export strategies with low-carbon initiatives can stimulate economic development while lowering carbon emissions Bonsu (2020). It is crucial to align export credit agencies' strategies with net-zero goals to facilitate the shift towards a low-carbon economy, promoting sustainable exports and reducing carbon-intensive production practices Hale et al. (2021).

Several countries in Sub-Saharan Africa rely significantly on industries like agriculture, mining, and fossil fuel extraction. The impact of remittances on these economies can either sustain or facilitate a shift away from activities that contribute to carbon-intensive economic activities Mohammed et al. (2013). Remittances can provide financial resources that empower local communities in economies where agriculture is a crucial sector. These funds can be used strategically to improve agricultural practices, promote eco-friendly methods, and invest in sustainable technologies. Redirecting remittances towards environmentally friendly farming techniques can reduce reliance on harmful conventional methods Wright et al. (2000). Remittances can be crucial in promoting responsible resource management in mineral-rich nations like Africa engaged in mining activities. By directing these funds towards investments in cleaner extraction technologies, stringent enforcement of environmental regulations, and sustainable mining practices, these countries can mitigate the environmental impact of mining and enhance long-term ecological sustainability Campbell (2006). Additionally, remittances can facilitate the shift towards renewable energy sources in regions heavily dependent on fossil fuel extraction. By allocating resources to support renewable energy initiatives, nations can diversify their energy sources, decrease reliance on fossil fuels, and contribute to global efforts to combat climate change Hu et al. (2019). Furthermore, remittances can have broader positive impacts by improving educational opportunities and access to information, fostering a more knowledgeable population that advocates for sustainable practices infrastructure Hussain et al. (2021).

Good governance is crucial for reducing CO_2 emissions as it enables the implementation of policies that support emission reduction targets and sustainable development. Countries with robust governance structures tend to have better environmental quality due to regulations and standards protecting the environment and mitigating carbon emissions Abid et al. (2021). Besides, good governance can enhance financial development by attracting private and foreign investments, which is essential for supporting initiatives to reduce carbon emissions Du et al. (2023). Efficient governance also contributes to institutional performance and regulatory structures that promote environmental sustainability Hale et al. (2022). Furthermore, governance quality influences policy implementation processes to ensure that outcomes align with environmental goals. Promoting good governance practices is essential for controlling corruption and upholding the rule of law in environmental decision-making to reduce carbon emissions Sarpong and Bein (2020).

Investing in renewable energy sources is crucial for Sub-Saharan Africa to transition away from traditional fossil fuels and reduce reliance on carbon-intensive energy. The region has various renewable options like solar, wind, hydroelectric, geothermal, and biomass, offering a chance to adopt sustainable energy alternatives. This shift can significantly reduce carbon emissions and environmental pressures (Kabeyi and Olanrewaju (2022). Technological advancements in energy efficiency tailored to Sub-Saharan Africa's needs are vital in optimizing resource use. Implementing smart grid and storage technologies can improve energy distribution and consumption, addressing energy access and reliability challenges Welsch et al. (2013). Carbon capture technologies can help reduce industry emissions, supporting the region's sustainable development goals. The adoption of electric mobility, driven by advancements in electric vehicles and charging infrastructure, tackles transportation issues and cuts emissions from the transport sector Kwilinski et al. (2023). Digitalization is crucial in modernizing energy systems in Sub-Saharan Africa, enhancing efficiency, resource management, and overcoming infrastructure limitations Ayakwah et al. (2021). Embracing circular economy principles is vital in the region to promote sustainable consumption and production patterns, encouraging material reuse and recycling to minimize waste and optimize resource use Giannetti et al. (2023).

2. LITERATURE SURVEY

2.1. Export Earnings and Zero Carbon Emission

Export earnings and zero carbon emissions are interconnected in a complex way. Countries that rely on exports may produce more carbon emissions from industry and transportation. However, there are also ways in which export earnings can support initiatives to lower or counteract carbon emissions. There are many studies that convey that export earnings promote zero carbon emissions (Elkins and Baker, 2001; Wang and Wang, 2020; Green, 2021; Huisingh et al., 2015). For instance, investing in green technologies and sustainable practices, such as renewable energy sources and eco-friendly production methods, can be funded by the increased export earnings of governments and businesses (Sarkar, 2013; Rokhmawati, 2021; Ye and Dela, 2023; Shaikh, 2017). One study by Wang et al. (2020a) proclaimed that economic diversification, driven by higher export revenues, can promote the growth of eco-friendly sectors. For example, exporting environmentally friendly products can help decrease carbon footprints. Meng et al. (2022) also profound that BRICS countries have many environmentally friendly products, and their export diversification has increased. This has positively impacted all income groups and has had a significant influence on various economic sectors. Countries that earn a lot from exports may use some of that money to support conservation and environmental protection initiatives, such as reforestation Gouyon (2003), wildlife conservation Ramesh and Rai (2017), and projects that help preserve natural ecosystems and address climate change (Wylie et al., 2016; Naumann et al., 2011). Not only that, many countries like Latin American nations invest a portion of their export earnings in carbon offset projects, which involve funding initiatives that capture or reduce greenhouse gas emissions, like afforestation, renewable energy projects, and sustainable agriculture (Wright et al., 2000; Khatri-Chhetri et al., 2021). Additionally, recent research in Africa has found that boosting export revenue can empower nations to participate in international partnerships that support sustainable trade practices. By focusing on environmental regulations and promoting eco-friendly production and transportation methods, countries can collectively reduce worldwide carbon emissions Nwokolo et al. (2023). Industries that focus on exporting goods may choose to implement eco-friendly supply chain practices to align with the sustainability demands of global markets Al-Ghwayeen and Abdallah (2018). This could include utilizing sustainable packaging, minimizing waste, and implementing energy-efficient transportation methods Bleischwitz et al. (2009). Countries with significant export earnings may invest in sustainable infrastructure like public transportation, renewable energy, and waste management to support reducing carbon emissions (Khan et al., 2020b; Zubedi et al., 2018).

The association between export earnings and carbon emissions is complex, and another piece of evidence suggests an antagonistic connection between export earnings and zero carbon emissions. Export earnings can lead to higher carbon emissions due to the energy-intensive processes, transportation, and production methods involved in international trade, contributing to an increased carbon footprint (Simas et al., 2015; Wang et al., 2019). Other than that, industries that focus on exporting goods, particularly in manufacturing, often rely on energy-intensive processes that result in increased carbon emissions. Producing goods for export typically involves using fossil fuels, releasing greenhouse gases into the atmosphere (Nguyen, 2022; Simas et al., 2015). Exporting goods often requires transporting them over long distances via various modes such as land, sea, or air. This transportation process, mainly using fossil fuel-powered vehicles or ships, can produce substantial carbon emissions. The farther the goods need to be transported, the higher the carbon footprint associated with the exported products Hu et al. (2019). Producing goods for export typically involves extracting and processing raw materials, particularly in industries such as mining and extraction. These activities are energy-intensive and have environmental consequences, including carbon emissions (Farjana et al., 2019; Hertwich, 2010). Using carbon-intensive energy sources like coal or natural gas to produce goods for export can significantly raise the total carbon footprint linked to those products Yang et al. (2016). Certain nations like Peru, Raihan and Tuspekova (2022) may increase their agricultural operations to satisfy the requirements of international markets. Clearing land for farming, mainly by cutting down forests, releases significant quantities of carbon dioxide into the atmosphere, contributing to climate change Meyfroidt and Lambin (2011). Global supply chains that are intricate and linked to export-focused manufacturing can result in inefficiencies and higher levels of carbon emissions. Multiple production and transportation stages contribute to a product's all-around carbon footprint Anderson (2022). In some cases, i.e., G7 nations with lax environmental regulations may draw industries with high carbon footprints because of lower costs, resulting in higher carbon emissions from producing goods for export Doğan et al. (2022). Additionally, a study in China unveiled that energy-intensive exported goods, such as electronic devices and heavy machinery, can increase carbon emissions in the countries where they are used Li et al. (2024).

2.2. Remittance and Zero Carbon Emission

Remittances, funds transferred by migrants, can indirectly positively impact reducing carbon emissions. Although the direct effect may be minimal, remittance inflows' economic and social benefits can result in favorable environmental outcomes. There are multiple studies by (Zhang et al., 2022; Dash et al., 2024; and Zhang et al., 2023) in which remittances can help in lowering carbon emissions. In the short term, increasing remittances to China positively impacts environmental sustainability. Findings also suggest recommendations to policymakers on using remittances effectively to promote green economic growth Zhang et al. (2023). In Nepal, recipients of remittances have the opportunity to invest in sustainable practices and technologies, such as renewable energy sources, energy-efficient appliances, and environmentally friendly agricultural methods, which can help reduce carbon emissions Sharma et al. (2019). In Latin American countries, including Brazil, remittances enable recipients to expand their sources of income by investing in sustainable economic activities, which can help communities decrease their reliance on high-carbon industries and ultimately reduce emissions (Liu et al., 2022; Duchelle et al., 2014). On the flip side to deforestation, remittance funds can actually support environmental conservation activities like reforestation, wildlife protection, and preserving natural ecosystems. These investments can help with carbon sequestration and biodiversity conservation Meyers et al. (2020). For instance, foreign investors in Ethiopia can transfer all profits from activities like carbon sequestration and biodiversity conservation Reynolds et al. (2010). Besides, a study by Ratha (2011) in Africa shows that remittances are crucial in enabling families to invest in education, leading to a well-educated population more likely to adopt sustainable practices. This can ultimately result in lower per capita carbon footprints over time. Additionally, remittances can contribute to poverty reduction and improved living standards, which may lead to communities shifting towards more sustainable and environmentally conscious consumption patterns Sikder and Higgins (2017). Remittances can undoubtedly increase communities' ability to withstand the effects of climate change. They offer financial support to help communities better prepare for environmental changes and develop resilient infrastructure that is resilient to climate-resilient infrastructure (Hussain et al., 2021; Hallegatte et al., 2020). Clearly, remittances can ease economic burdens on local resources, potentially reducing strain on ecosystems and preventing overexploitation of natural resources, deforestation, and activities leading to higher carbon emissions Mancini et al. (2019). These funds can also be utilized to back community-based renewable energy initiatives, such as setting up solar or wind energy facilities as cleaner alternatives to conventional energy sources Bisaga and To (2021).

Nevertheless, conversely, conflicting findings suggest that remittance may be accountable for carbon emissions. Recipients of remittances in Asian economies frequently use the funds to enhance their standard of living, resulting in a rise in consumer spending on items with significant carbon footprints, like electronic devices, vehicles, and energy-intensive products Liu et al. (2023). A study by Ramakrishnan et al. (2020) in India uses data from the India Human Development Survey (IHDS) in 2005 and 2012 to analyze the impact of social and economic, demographic, locational, and housing factors on household ownership levels. The research indicates that the increased remittance in India is linked to higher consumption of cars and appliances, influenced not only by economic factors but also significantly by social factors, particularly the household's perception of status. The study highlights the role of conspicuous consumption expenditure in driving the adoption of these products, suggesting that as remittance increases, households are more likely to engage in status-driven consumption. Another study by Zaman et al. (2013) in Pakistan examines the connection between critical macroeconomic factors and rising energy consumption in Pakistan from 1980 to 2011. The study uses statistical methods like cointegration, error correction models, and Granger causality tests to understand these variables' long-term relationships, short-term dynamics, and causal links. The findings highlight the impact of Tetra-partner power and energy-intensive industries on Pakistan's economic growth, leading to a notable increase in electricity consumption and remittances. However, the study also raises concerns about the societal impact, pointing towards addressing the potential detrimental effects on society.

Remittance funds have been used for construction projects, such as building bigger houses and commercial buildings. This has caused a surge in demand for cement and other construction materials, leading to higher carbon emissions from their production and transportation. For instance, Jordan has witnessed using remittance funds for construction projects, particularly for expanding larger houses and commercial buildings. This has led to a rise in carbon emissions, emphasizing the environmental consequences of using remittance funds for such development activities Hamouri (2020).

2.3. Good Governance and Zero Carbon Emission

Myriad researchers (Kor and Qamruzzaman, 2023; Karim et al., 2023; Ju et al., 2023; JinRu et al., 2023; Islam et al., 2023; Farzana et al., 2023) assert that good governance is essential for reducing carbon emissions as it creates a supportive framework for sustainable actions, enforces rules, and promotes clean technologies. A study in sub-Saharan Africa revealed that effective environmental policies are a vital component of good governance, requiring transparent and accountable institutions to develop and enforce regulations that aim to reduce emissions, encourage the use of renewable energy, and establish industry environmental standards Sarpong and Bein (2020). Additionally, a study by Omri and Mabrouk (2020) in 20 selected MENA economies for 1996-2014. Employing a simultaneous-equation modeling approach, proclaimed that good governance, characterized by transparency, accountability, and adherence to the rule of law, plays a crucial role in reducing carbon dioxide emissions within the framework of human development. Improved political and institutional governance is critical to addressing and minimizing carbon emissions. Countries like China, with effective governance systems, are more inclined to focus on and allocate resources to renewable energy sources. By implementing favorable policies, incentives, and well-defined regulations, governments can promote advancing and adopting renewable energy technologies, ultimately decreasing reliance on non-renewable fossil fuels Du et al. (2023).

Effective governance involves defining specific goals for reducing emissions and implementing robust monitoring systems. Continuous monitoring and reporting of carbon emissions by various industries and sectors are essential for tracking progress and holding stakeholders accountable Al Sadawi et al. (2021). Governments play a crucial role in promoting sustainability in agriculture, transportation, and construction by advocating for energy-efficient technologies, sustainable farming practices, and environmentally friendly building standards to reduce carbon footprints (Serfraz et al., 2023; Lin and Qamruzzaman, 2023; Li and Qamruzzaman, 2023). As a case in point, research by Hepburn et al. (2021) found that the 14th 5-year Plan of China (2021-2025) is a significant chance to align long-term climate objectives with current social and economic strategies. While China has pledged to achieve carbon neutrality by 2060, this analysis stresses the importance of implementing more robust short-term climate measures, especially in areas like energy transition, sustainable urban growth, and strategic investments following the COVID-19 pandemic. It advocates for China to reach peak emissions.

Good governance plays a crucial role in promoting the development of efficient public transportation systems and sustainable urban planning. This involves investments in public transit, cycling infrastructure, and pedestrian-friendly cities to reduce reliance on individual cars and decrease carbon emissions De Guimarães et al. (2020). Good governance also involves engaging in international cooperation and agreements, such as the Paris Agreement, to address climate change on a global scale. Implementing carbon pricing mechanisms, like carbon taxes or cap-and-trade systems, provides economic incentives for businesses to reduce their carbon footprint. Besides, transparent governance includes community engagement and education on sustainable practices to encourage citizen involvement in climate action Morgan and Patomäki (2021). Governments can also incentivize green innovation through research and development of renewable energy, energy storage, and sustainable agriculture technologies to facilitate a transition to a low-carbon economy. Conversely, other researchers have conflicting findings, asserting that effective governance could lead to higher levels of carbon emissions in certain situations. Namely, Ran et al. (2020) and Sun and Huang (2020), in some cases, good governance may not always effectively reduce carbon emissions, whereas less restrictive regulations could have a more significant impact.

Governance focusing on immediate economic benefits rather than long-term environmental sustainability may encourage carbon-intensive industries like fossil fuel extraction and heavy manufacturing, resulting in increased emissions Napp et al. (2014). Governance that prioritizes economic development without considering sustainability can lead to infrastructure projects that increase emissions, such as carbon-intensive transportation systems Lah (2017). Strong governance may sometimes result in land use policies that promote deforestation and unsustainable agricultural practices, releasing carbon into the atmosphere Lambin et al. (2014). Additionally, consumer-oriented economic policies that do not account for environmental impacts can encourage carbon-intensive consumption patterns Schanes et al. (2016). Neglect of sustainable urban planning can lead to higher emissions from individual vehicle transportation in sprawling cities. A study showed that inefficient waste management practices in African nations can also contribute to emissions by releasing greenhouse gases from decomposing waste Friedrich and Trois (2011). Failure to address climate-related risks even after incorporating effective governance can increase emissions from recovery and reconstruction efforts after disasters Urban et al. (2011). Lastly, a lack of investment in green technologies and research and development can hinder the transition to cleaner and more sustainable practices, indirectly contributing to higher emissions Söderholm (2020). For instance, a South Asian study by Fang et al. (2022) determined that the limited availability of clean energy technologies and emissions reduction solutions can constrain industries and communities in their efforts to comply with strict environmental standards. This can pose challenges for governance enforcing regulations, as the lack of viable alternatives may lead to higher carbon emissions.

2.4. Innovation and Zero Carbon Emission

Innovation is essential for reducing carbon emissions by developing new energy-efficient, sustainable, and environmentally friendly technologies, processes, and solutions. The research primarily focuses on innovation as technological advancements that drive progress and reshape industries, emphasizing technology's transformative impact on societal and economic development. Considerable researchers argue that advancements in technology have the potential to help decrease carbon emissions (Yin and Qamruzzaman, 2024; Qamruzzaman, 2024). Progress in renewable energy technologies like solar, wind, hydro, and geothermal offer cleaner options than fossil fuels. These systems' improved efficiency and affordability drive their widespread use, decreasing dependence on carbon-heavy energy sources. Additionally, advancements in energy storage solutions, like advanced batteries, support the adequate storage and use of renewable energy. This helps manage the intermittent nature of some renewable sources and enhances the stability and reliability of clean energy grids Li and Wang (2017).

Another research by Dominković et al. (2018) in the EU shows that progress in battery technology and charging infrastructure further supports the transition to cleaner and more sustainable transportation options. Carbon Capture and Storage (CCS) technologies capture carbon dioxide emissions from industrial processes and power plants to reduce greenhouse gas emissions from sectors that are difficult to decarbonize fully Paltsev et al. (2021). Innovative grid technologies improve energy distribution and consumption efficiency. At the same time, demand response systems enable better management of energy consumption during peak periods to optimize energy use and reduce carbon emissions Hafeez et al. (2020). For instance, a survey study by Siano (2014) established that Demand Response (DR) is a strategy that helps reduce peak energy demand and lower carbon emissions in the long run. This is achieved by improving energy efficiency through technologies such as automatic energy schedulers, which optimize energy consumption.

Innovative building technologies such as intelligent HVAC systems, energy-efficient insulation, and automated energy management systems effectively decrease energy usage in residential, commercial, and industrial buildings Hossain et al. (2023). These advancements play a significant role in reducing carbon emissions related to heating, cooling, and lighting. Similarly, advancements in sustainable agriculture practices, such as precision agriculture, sensor technologies, and data analytics, help improve farming methods by reducing the use of fertilizers and pesticides, minimizing energy-intensive processes, and promoting sustainable land management, resulting in lower emissions from the agriculture sector Ashraf et al. (2021). Advancements in Indian agriculture, particularly in Telangana and Andhra Pradesh, have shown promising results in reducing carbon emissions by adopting energy-efficient practices. These innovations have led to significant decreases in pesticide usage and fertilizer consumption, highlighting the potential of modern agricultural techniques to promote environmental sustainability Mehta et al. (2020). Technological advancements in recycling, waste-to-energy processes, and cleaner industrial technologies are vital in promoting a circular economy and reducing waste disposal's environmental impact Boloy et al. (2021). These innovations help minimize carbon emissions linked to landfilling and incineration while also contributing to lower emissions from industrial activities through cleaner manufacturing processes, electrification of equipment, and using sustainable materials contribute to reducing carbon emissions from industrial activities Colangelo et al. (2023).

Other researchers hold differing opinions, indicating that innovation could result in higher levels of carbon emissions in certain situations. Technological advancements are typically intended to lower carbon emissions, but there are cases where they may unintentionally lead to higher emissions. In particular, improvements in energy efficiency can lead to a rebound effect where the cost savings from efficiency gains are reinvested in additional consumption. For illustration, in EU nations, more fuel-efficient cars lead to augmented travel, partially offsetting the emissions reductions Fontaras et al. (2017). Rapid technological advancements can result in shorter product lifespans and more frequent turnover of electronic devices. These items' production, transportation, and disposal can lead to more significant emissions, mainly if recycling practices need to be improved Fontaras et al. (2017). A questionnaire survey data collected from 426 participants showed that adopting specific technologies, such as ride-sharing apps, could increase carbon emissions by influencing consumer behavior towards more individual transportation services Wang et al. (2020b). Manufacturing advanced technologies like electric vehicles, solar panels, and batteries requires much energy, resulting in a high carbon footprint if non-renewable energy sources are used Mohideen et al. (2023). Adopting certain agricultural technologies can result in higher emissions if not used sustainably. These technologies include energy-intensive machinery, overuse of fertilizers, and unsustainable irrigation methods Mallareddy et al. (2023).

2.5. Literature Gap and Contribution

The existing literature on carbon emissions in Sub-Saharan African countries acknowledges the significance of good governance and innovation. Still, it lacks a detailed analysis of how specific governance structures influence efforts to reduce carbon emissions. It is essential to understand the nuances of governance systems and their impact on environmental sustainability in different national contexts. Research on the effectiveness of innovation in reducing carbon emissions in Sub-Saharan Africa is limited, highlighting the need to identify successful innovative practices, technologies, and strategies for informing future policy decisions. Similarly, there needs to be more understanding of how remittances impact carbon reduction strategies, emphasizing the importance of investigating the role of remittances in supporting or impeding environmentally friendly initiatives to guide policy development. Research is required to determine how export earnings affect the funding of green investments and the development of renewable energy sources. Understanding the long-term sustainability of renewable energy projects is essential to inform future policy decisions. Research in Sub-Saharan Africa highlights a need to address institutional barriers hindering the effectiveness of climate policies despite efforts like the Kyoto Protocol. Understanding these challenges is crucial for developing more robust environmental frameworks. More research is needed to explore how communities can actively participate in environmental initiatives and influence policy. Additionally, limited research examines the gender dimensions of carbon reduction efforts in the region, which could provide insights for creating more inclusive strategies.

This study provides insights into the challenges and opportunities unique to Sub-Saharan African countries regarding the journey towards zero carbon emissions. It aims to explore the impact of governance dynamics on environmental sustainability, identify innovation pathways for sustainability, examine the role of remittances in environmental stewardship, and offer guidance on balancing export-led growth with sustainability in the region.

2.6. Theoretical Underpinning and Conceptual Development

The interconnection between revenue generated by exports, renewable energy, money sent back home by migrants, and the pursuit of eliminating carbon emissions is a crucial research subject in the context of nations in sub-Saharan Africa. The connection between good governance and innovation is crucial in harmonizing these factors to attain sustainable development. This section presents a theoretical foundation and conceptual framework that supports the empirical study of these interactions.

The theoretical foundation is based on the modernization theory, which suggests that achieving economic progress is essential for ensuring environmental sustainability. It implies that as economies expand—through higher export revenues and the flood of remittances—they gather the resources and the will to invest in cleaner energy sources and strive for environmental objectives such as carbon neutrality. The Environmental Kuznets Curve (EKC) hypothesis complements the modernization theory. It proposes that as a nation's wealth increases, environmental degradation initially increases until it reaches a peak, after which it starts to decline. This hypothesis suggests an inverted U-shaped relationship between environmental degradation and economic growth. The United Nations Development Programme defines good governance as a set of concepts, including participation, transparency, accountability, effectiveness, and equality, that are crucial for achieving sustainable development. Effective governance guarantees the effective implementation of environmental and economic regulations, sustainable management of resources, and equitable distribution of the benefits of innovation and economic progress. The Schumpeterian growth theory asserts that economic development is primarily driven by technical innovation and the spread of knowledge. Innovation plays a crucial role in this theory. Within the sub-Saharan Africa region, innovation has the potential to promote the advancement of clean energy technology, optimize resource use, and aid in the mitigation of carbon emissions. Please see the Figure 1

3. DATA AND METHODOLOGY OF THE STUDY

3.1. Model Specification

The motivation of the study is to gauge the nexus between Export earnings, Remittance, good governance, clean energy, innovation, and carbon neutrality in sub-Saharan African countries for the period 2001-2020. The generalized equation for the empirical relations is as follows:

$$CO_2 | EX, REM, GG, INN, CE \quad (1)$$

After transformation with natural log, Eq (1) can be displayed in the following manner Eq (2).

$$CO2it = \beta_0 + \beta_1 EX_{it} + \beta_2 REM_{it} + \beta_3 GG_{it} + \beta_4 INN_{it} + \beta_5 CE_{it} + \epsilon_i \quad (2)$$

Where β_0 is the intercept term. β_1, β_2, β_3, β_4, and β_5 are the coefficients that represent the relationship between carbon dioxide emissions and each of the independent variables. ϵ_i represents the error term, which captures the unexplained variation in carbon dioxide emissions not accounted for by the independent variables. The possible ways of effect from independent variables displayed in Figure 2.

3.2. Variables Definition and Expected to Sing

The first explanatory variable is *export earnings* (EX), which measures the total earnings from exports in country i at time t. It reflects the economic activity generated by international trade Brambilla et al. (2012). The sign is unclear. Although higher export

Figure 1: Theoretical development of the study

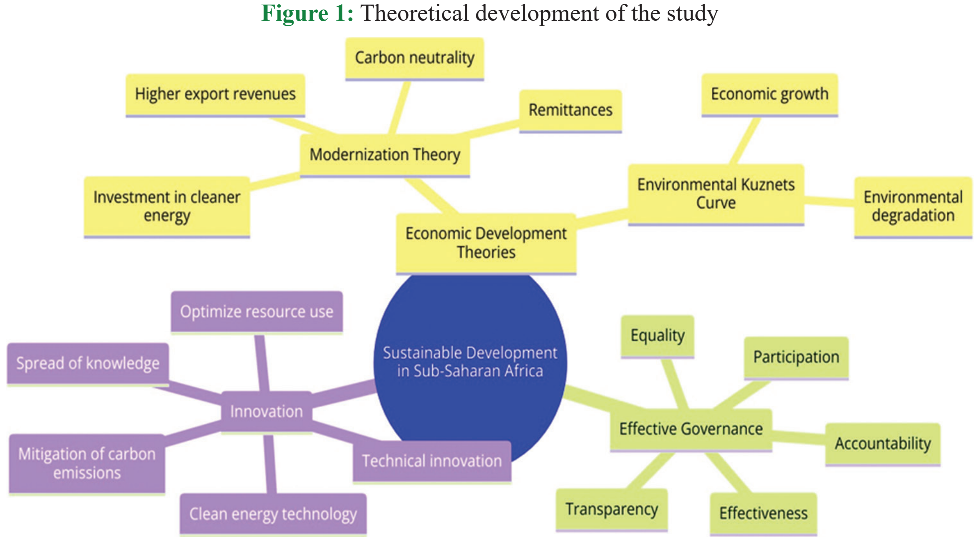
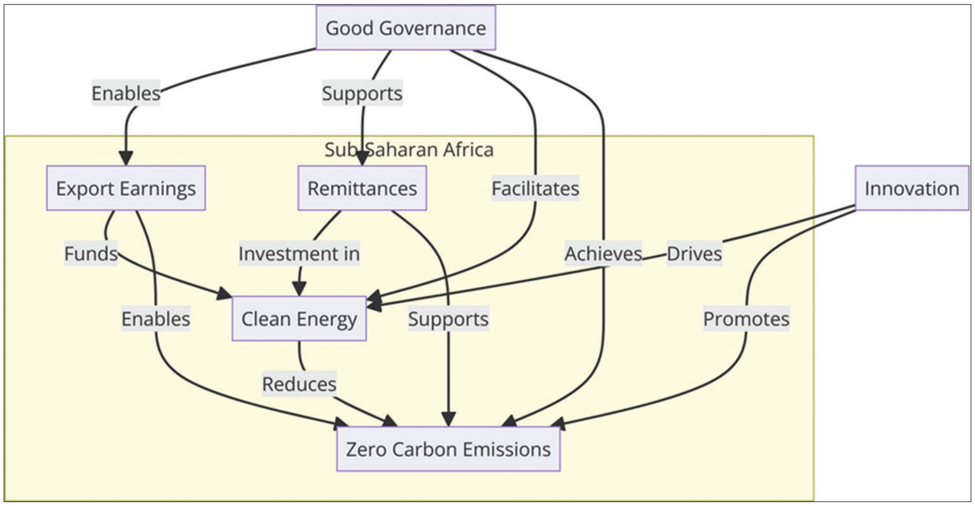


Figure 2: The possible connect to CO_2 neutrality



earnings may suggest a rise in economic activity, which could increase carbon emissions, it could also encourage investments in cleaner technologies and sustainable practices, potentially lowering emissions Lee (2013).

The second explanatory variable is *remittance* (REM), which refers to the money sent by migrants back to their home country, usually to provide financial assistance to family members or for investment activities. The sign is also positive Hagen-Zanker and Siegel (2007). Remittances have the potential to impact economic growth and development, which can, in turn, affect energy consumption and carbon emissions. They can contribute to increased emissions through economic growth or support investments in clean energy and sustainable development, leading to lower emissions Saliba et al. (2022).

The third explanatory variable is *good governance* (GG), a comprehensive indicator that assesses the effectiveness of governance by considering elements like transparency, accountability, adherence to the rule of law, and the prevention of corruption Srivastava (2009). The expected sign is negative. Countries with adequate governance practices will likely implement policies and regulations promoting environmental sustainability and lowering carbon emissions Haque and Ntim (2018).

The fourth explanatory variable is *innovation* (INN), which measures how advanced a country is in technology and how much it adopts new technologies and processes at a specific time t Sirilli and Evangelista (1998). The expected sign is negative. The negative sign indicates that increased innovation will likely result in improved uptake of cleaner technologies, ultimately decreasing carbon emissions from economic activities Sovacool et al. (2022).

The fifth explanatory variable is *clean energy* (CE). This metric quantifies the percentage of energy produced from sustainable sources like solar, wind, hydro, and geothermal energy in a specific country at a given time t Shahzad et al. (2023). The expected sign is negative. Using cleaner energy sources will likely decrease carbon emissions due to reduced dependence on fossil fuels and other high-carbon energy sources Kartal (2022).

The dependent variable is the *carbon dioxide* (CO_2) emitted by country i at time t. It measures the environmental impact of greenhouse gas emissions Gavurova et al. (2021). It is anticipated that there will be a positive relationship. A rise in carbon dioxide emissions is likely linked to increased economic activity, as shown by export earnings and remittances, unless counteracted by initiatives encouraging cleaner energy and innovation Khan et al. (2022).

3.3. Estimation Strategies

CD test of Juodis and Reese (2022).

Consider the weighted CD test statistic

$$CD_W = \left(\frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{\varepsilon}_{i,t}^2 w_i^2\right)^{-1} \left(\sqrt{\frac{2}{TN(N-1)}}\sum_{t=1}^{T}\sum_{i=2}^{N}\sum_{j=1}^{i-1} w_i\hat{\varepsilon}_{i,t} w_j \hat{\varepsilon}_{j,t}\right) \quad (3)$$

And assume that either of the following two points hold.

1. The data are generated by the time fixed-effects model (4) such that Assumption 1 holds. $\hat{\varepsilon}_{i,t}$ Is given by Equation (6).
2. The latent standard factor model (16) generates the data such as Assumptions 2-6 hold. $\hat{\varepsilon}_{i,t}$ It is defined by Equation (20).

It holds that under either of the two sets of assumptions above, as well as Assumption 7.

$$CD_W \xrightarrow{d} N(0,1)$$

as $N,\ T \rightarrow \infty$ jointly subject to the restriction $\sqrt{T}N^{-1} \rightarrow 0$.

SH test of Bersvendsen and Ditzen (2021).

$$H_0: \theta_1 = 0 \quad (4)$$

$$t_{SH} = \frac{\hat{\theta}_1}{SE_{\hat{\theta}_1}} \quad (5)$$

$$p - value = P\left(t_{HS} > \left|t_{HS}\right|\right) \quad (6)$$

Integration (or unit-root) test of Herwartz and Siedenburg (2008)

$$H_0: \delta = 0 \quad (7)$$

$$t_{SH} = \frac{\hat{\delta}_1}{SE_{\hat{\delta}_1}} \quad (8)$$

$$p - value = P\left(t_{HS} > \left|t_{HS}\right|\right) \quad (9)$$

Cointegration test of Wester Lund and Edgerton Pedroni (2004) develops residual-based cointegration test statistics for heterogeneous dynamic panels. The Author discussed asymptotic properties, conducted finite sample analysis, and explored relevance to the Purchasing Power Parity hypothesis. Besides, Kao (1999) explores the asymptotic properties of the least-squares dummy variable (LSDV) estimator and other standard statistics in spurious panel data regressions. Utilizing residual-based cointegration tests such as Dickey-Fuller (DF) and modified DF tests, the study employs asymptotic distributions and Monte Carlo experiments to evaluate finite sample quality and comprehend spurious regression in the panel.

Westerlund (2005; 2007) utilized a panel cointegration test to investigate the association among variables over an extended period. Westerlund's error correction-based cointegration test was another method they used in their experiments. With the help of two different sets of test statistics, the research endeavored to test the null hypothesis that there was no cointegration.

$$\Delta Z_{it} = \partial_i d_i + \varnothing_i \left(Z_{i,t-1} - \delta_i W'_{i,t-1} \right) + \sum_{r=1}^{p} \varnothing_{i,r} \Delta Z_{i,t-r} + \sum_{r=0}^{p} \gamma_{i,j} \Delta W_{i,t-r} + \varepsilon_{i,t} \quad (10)$$

$$G_T = \frac{1}{N} \sum_{i-1}^{N} \frac{\varphi_i}{SE\varphi_i} \quad (11)$$

$$G_T = \frac{1}{N} \sum_{i-1}^{N} \frac{T\varphi_i}{\varphi_i(1)} \quad (12)$$

$$P_T = \frac{\varphi_i}{SE\varphi_i} \quad (13)$$

$$P_a = T\varphi_i \quad (14)$$

DCE:

The following equations give the DCE model of the economy described above:

$$c_t / \left(1 - n_t\right) = \frac{\mu_1}{\mu_2}\left(1 - \tau_t^l\right) w_t \quad (15)$$

$$U_{c_t} = \beta U_{c_t+1}\left[\left(1 - \tau_{t+1}^k\right) r_{t+1} + 1 - \delta^k\right] \quad (16)$$

$$Q_{t+1} = \left(1 - \delta^q\right)\overline{Q_t} + \delta^q Q_t - \phi A k_t^\alpha n_t^{1-\alpha} + vgt \quad (17)$$

$$c_t + k_{t+1} = A k_t^\alpha n_t^{1-\alpha} - gt + \left(1 - \delta^q\right) k_t \quad (18)$$

The DCE model is based on primary provisions for the variables of K_0 and Q_0 with first-order conditions of the sample firm problem, with endogenous variables A and ϕ with the given policy (τ^k, τ^l) which has resulted in $r_t = a_t n_t$ and $w_t = (1-a) A_t^a D_t^{-a}$. Then, we have a system containing five equations as $\{c_t, n_t, k_{t+1}, Q_{t+1}, g_t\}_{t=0}^{\infty}$ If we discard the subscript t, we can also get a long-term DCE.

The Dumitrescu-Hurlin (DH) panel causality model is articulated as follows:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma ik\, yi,t-k + \sum_{k=1}^{K} \beta ik\, xi,t-k + \varepsilon_{i,t}\, with\, i = 1,\ldots,N\, and\, t = 1,\ldots,T \quad (19)$$

In equation (2), $x_{i,t}$ and $y_{i,t}$ Represent the observations of two stationary variables for individual *i* in period *t*. The coefficients can vary across the individual sample while remaining time-invariant, and the lag order *K* is assumed to be uniform across the panel. It is further assumed that the panel is balanced. The null hypothesis is stated as:

$$H_0 : \beta_{i1} = \ldots = \beta_{ik} = 0 \forall_i = 1, \ldots, N$$

The model implies the absence of a specific direction of causality for all individuals in the panel. The DH test also assumes that there can be a causal link between some variables and not necessarily all. Therefore, the alternative hypothesis is formulated as:

$$H_1 : \beta_{i1} = \ldots = \beta_{ik} = 0 \forall_i = 1, \ldots, N_1$$

$$\beta_{i1} \neq 0 or \ldots or \beta_{ik} \neq 0 \forall_i = N_1 + 1, \ldots, N$$

Where $N_1 \in [0, N–1]$ is unknown. If N_1 is equal to 0, there is a causal link among the individual variables in the panel, and N_1 must be strictly > *N*.

4. ESTIMATION AND INTERPRETATION

Table 1 presents the results of diverse tests performed to analyze the properties of the variables CN (Clean Energy), EX (Export Earnings), REM (Remittance), INN (Innovation), GG (Good Governance), CE (Carbon Emissions), and CO_2 (Carbon Dioxide Emissions). These tests include the CD test for cointegration, the SH test for structural breaks, and the unit-root test for assessing stationarity.

For Panel A, we conducted the Juodis and Reese (2022) CD test, which is used to determine cointegration among the variables, implying a long-term relationship between them. The test results show that all variables have significant values at the 1% level (denoted by ***), indicating strong evidence of cointegration.

The SH test of Bersvendsen and Ditzen (2021) detects structural breaks in time series data, which signify relationship changes between variables over time. The Delta Statistic and Adjusted Delta Statistic show significance at the 1% level (***), indicating the presence of structural breaks.

Panel C presents the results of the Integration (or Unit-Root) Test by Herwartz and Siedenburg (2008), which assesses the stationarity of variables through unit-root tests. Stationarity refers to the consistent behavior of variables over time. The test shows significant values at different levels for various variables, indicating different stationarity characteristics. Some variables exhibit non-stationarity at the level but become stationary, while others remain non-stationary even after differencing.

The analysis suggests a consistent, enduring connection between Clean Energy, Export Earnings, Remittance, Innovation, Good Governance, Carbon Emissions, and Carbon Dioxide Emissions in sub-Saharan African countries. This indicates changes in economic, environmental, and policy factors. Some variables may need adjustment to achieve stability, while others may exhibit non-stationary behavior.

Table 2 presents the results of cointegration tests conducted employing the methodologies proposed by Westerlund and Edgerton (2008) and Westerlund and Edgerton (2007), respectively. For panel A, Westerlund and Edgerton (2008) test statistics and their corresponding P-values are used to assess the significance of cointegration in various situations. A P-value below a specified significance level, typically 0.05 or 0.01, indicates the existence of cointegration. A statistically significant outcome suggests a lasting connection between the variables examined, implying that they move together in the long run. The LMr and LMΦ test statistics are both statistically significant ($P < 0.05$) under this scenario, exhibiting the presence of cointegration between the variables even without considering any shift in the data. This implies a long-term relationship among the variables tested. With the inclusion of a mean shift in the data, the LMr and LMΦ statistics remain statistically significant ($P < 0.05$). This implies that even when accounting for a mean shift, the cointegration relationship persists, indicating a stable long-term association among the variables. Similarly, when evaluating a regime shift in the data, both LMr and LMΦ test statistics remain statistically significant ($P < 0.05$). This suggests the cointegration relationship holds even in a regime shift, showing a consistent long-term connection among the variables.

Similarly, for panel B, the cointegration test Westerlund and Edgerton (2007) in this panel delivers results for different models and specifications. For each model, the test statistics (Gt and Ga) are all statistically significant ($P < 0.05$ or $P < 0.01$), suggesting cointegration between the variables in the respective models. These results imply that regardless of the model specification or type of test (Pt or Pa), there is strong evidence of a long-term relationship among the variables tested, backing the idea that they move together over time.

The table displays the estimation outcomes of an empirical model under two distinct specifications: DCE (Dynamic Panel Data Model with Common Effects) and DCE-IV (Dynamic Panel Data

Table 1: Results of SH test, CSD test, and panel unit root test

Panel A: CD test of Juodis and Reese (2022)							
Test	**CN**	**EX**	**REM**	**INN**	**GG**	**CE**	**CO_2**
Test value	1.7062***	−1.1856***	5.2434***	−7.7959***	−1.1906***	6.2149***	−5.4679***
Probability	***	***	***	***	***	***	***
CD exist	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel B: SH test of Bersvendsen and Ditzen (2021)							
Test	**Delta statistic**	**Adjusted delta statistic**	**SH exits**				
Model	3.0381***	4.5685***	Yes				
Panel C: Integration (or unit-root) test of Herwartz and Siedenburg -2008							
Test	**CN**	**EX**	**REM**	**INN**	**GG**	**CE**	
At level	0.3272	1.0933	1.537	0.5045	−0.7853	0.354	
First difference	−4.4249***	−3.2572***	3.2941***	7.5619***	−1.3842***	−1.6732***	

CN: Clean energy, EX: Export earnings, REM; Remittance, INN: Innovation, GG: Good governance, CE: Carbon emissions, CO_2: Carbon dioxide emissions

Table 2: Results of panel cointegration test

Panel A: Cointegration test of Westerlund and Edgerton (2008)						
Test	**No shift**		**Mean shift**		**Regime shift**	
	LMr	**LMΦ**	**LMr**	**LMΦ**	**LMr**	**LMΦ**
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Statistic**
Model 1	−3.707***	−2.743***	−4.6564***	−4.3092***	−2.9388***	−4.2625***
Panel B: Cointegration test of Westerlund and Edgerton (2007)						
Model	**Gt**	**Ga**	**Pt**		**Pa**	
FDI→EC	−11.012***	−13.128***	−15.35***		−13.614***	

Model with Common Effects and Instrumental Variables). Results displayed in Table 3 appears to list coefficients from a statistical model with the dependent variable being "carbon neutrality," presumably measured by CO_2 emissions or absorption levels. Two different models are presented: DCE and DCE-IV. These could stand for "Dynamic Conditional Expectation" and "Dynamic Conditional Expectation - Instrumental Variables" respectively, or similar modeling techniques.

For, CN (−1), which is likely referring to the lagged value of the dependent variable, carbon neutrality from a previous time period. Negative coefficients in both models (−0.1145 and −0.17922) suggest that higher past values of carbon neutrality are associated with lower current values, which could imply a negative autocorrelation over time.

Referring to the coefficients of independent variables, for export earning, a positive coefficient in both models (0.14045 and 0.13849), suggesting that as EX increases, carbon neutrality also increases. Without context, it's hard to say what EX stands for, but it might represent external investment, export levels, or something similar that is hypothesized to improve carbon neutrality. Furthermore, REM has positive coefficients (0.10081 and 0.15637), indicating a similar relationship as EX, where an increase in REM is associated with an increase in carbon neutrality.

On the other hand, the contributory effects of innovation, good governance, and clean energy towards achieving the carbon neutrality have revealed. Particularly, INN shows negative coefficients (−0.08953 and −0.09558) in both models. Whatever INN represents, its increase seems to be associated with a decrease in carbon neutrality. Additionally, governmental effectiveness has a negative coefficient in the DCE model (−0.13396) and a positive one in the DCE-IV model (0.1558). This might suggest that the relationship between GG and carbon neutrality is complex and could be subject to endogeneity issues, which the instrumental variables in DCE-IV are attempting to address. Finally, similar to INN, CE is associated with a decrease in carbon neutrality across both models, with coefficients of −0.18268 and −0.13621.

The Table 4 presents the results of the Durbin-Hausman (D-H) causality test, which analyzes the causal relationships between carbon dioxide (CO_2) emissions and various independent variables, including exports (EX), remittances (REM), technological innovation (TI), good governance (GG), and clean energy (CE). Each cell in the table displays the test statistic for the D-H test, denoted in parentheses, along with asterisks exhibiting the significance levels (* for 10%, ** for 5%, and *** for 1%). A positive test statistic indicates that the independent variable causes changes in CO_2 emissions, while a negative test statistic indicates the reverse causality. For instance, the statistically significant test statistic of (6.2656) *** for the relationship between CO_2 and exports (EX) implies that EX significantly influences CO_2 emissions. Contrariwise, the test statistic of (1.916) * for the relationship between EX and CO_2 indicates that EX also causes

Table 3: Empirical model estimation with dynamic panel data model with common effects and dynamic panel data model with common effects and instrumental variables

Variables	DCE			DCE-IV		
	Coefficient	SE	T-statistic	Coefficient	SE	T-statistic
CN (−1)	−0.1145	0.0211	−5.4265	−0.17922	0.0382	−4.6916
EX	0.14045	0.0463	3.0334	0.13849	0.0288	4.8086
REM	0.10081	0.017	5.9311	0.15637	0.0203	7.7029
INN	−0.08953	0.0297	−3.0144	−0.09558	0.0399	−2.3954
GG	−0.13396	0.0451	−2.9702	0.1558	0.045	3.4622
CE	−0.18268	0.0375	−4.8714	−0.13621	0.02	−6.8105
c	−10.855	0.24013	−45.2046	−12.285	0.24013	−51.1597
R2	0.8952			0.9096		
Adj R^2	0.9468			0.9403		

DCE: Dynamic panel data model with common effects, DCE-IV: Dynamic panel data model with common effects and instrumental variables, SE: Standard error, CN: Clean energy, EX: Export earnings, REM; Remittance, INN: Innovation, GG: Good governance, CE: Carbon emissions, CO_2: Carbon dioxide emissions

Table 4: Results of D-H causality test

Variables	CO_2	EX	REM	TI	GG	CE
CO_2		6.2656***	2.7279*	3.5483**	4.3315**	5.8289***
		6.604	2.8752	3.7399	4.5654	6.1436
EX	1.916*		4.2624**	3.3995**	2.1902*	***
	2.0195		4.4926	3.5831	2.3084	5.7393
REM	5.085***	3.7151**		1.2901	4.0148**	1.9043*
	5.3596	3.9158		1.3597	4.2316	2.0071
TI	2.6524*	1.0573	1.0573		4.763***	2.188*
	2.7957	1.1144	1.1144		5.0202	2.3062
GG	1.0297	2.0244*	4.967***	3.9171**		3.3453**
	1.0853	2.1337	5.2352	4.1286		3.526
CE	1.3358	1.7236	2.4357*	1.476	5.2571***	
	1.4079	1.8167	2.5672	1.5557	5.541	

CE: Clean energy, GG: Good governance, TI: Technological innovation, REM: Remittances, EX: Export earnings, CO_2: Carbon dioxide emissions

Table 5 : Results of Robustness test with different techniques: MG, AMG, and CS-ARDL

Variables	MG			AMG			CS-ARDL		
	Coefficient	SE	T-statistic	Coefficient	SE	T-statistic	Coefficient	SE	T-statistic
EX	0.1614	0.0091	17.7362	0.0291	0.0072	4.0416	0.1332	0.0031	42.9677
REM	0.0726	0.0042	17.2857	0.0949	0.0067	14.1641	0.1075	0.0049	21.9387
INN	0.0414	0.0095	4.3578	0.0712	0.0052	13.6923	0.0776	0.0058	13.3793
GG	0.0903	0.0104	8.6826	0.103	0.0037	27.8378	0.0523	0.007	7.4714
CE	−0.124	0.0093	−13.3333	−0.1738	0.0112	−15.5178	−0.0477	0.0022	−21.6818
c	6.9307	0.816	8.4935	2.9894	0.611	4.8926	7.6675	0.2329	32.9218
CD test		0.0268			0.0227			0.029	
Wooldridge test		0.0255			0.0278			0.0328	
Normality test		0.0274			0.0203			0.0241	
Remsey reset test		0.0225			0.0202			0.0313	

SE: Standard error, REM: Remittances, EX: Export earnings, CO_2: Carbon dioxide emissions, CE: Clean energy, GG: Good governance

Table 6: Results endogeneity issue assessment: IV estimation

Variables	Coefficient	SE	T-statistics
EX	0.0925***	0.0134	−2.7205
REM	0.1536***	0.0341	−4.5176
INN	−0.167***	0.0244	−6.8442
GG	−0.0861***	0.0175	−4.9271
CE	−0.1434***	0.0176	8.1477
Anderson canonical correlation LM statistics		15.3134	
Cragg-Donald Wald F-statistics		1628.9251	
Stock-Yogo weak ID test critical values		18.99	

REM: Remittances, EX: Export earnings, CO2: Carbon dioxide emissions, CE: Clean energy, GG: Good governance, SE: Standard error

changes in CO_2 emissions, although at a lower significance level than other variables like REM and GG.

Following section deals with robustness assessment with MG, AMG and, CS-ARDL (see Table 5). For MG (holding other variables fixed at their average), the coefficient for TI is 0.1614, suggesting that a one-unit increase in technological innovation is associated with a rise of 0.1614 units in CO_2 emissions. The coefficient of REC is 0.0726, implying that a one-unit increase in renewable energy consumption leads to a 0.0726-unit rise in CO_2 emissions. The coefficient for FI is 0.0414, indicating that a one-unit increase in financial innovation results in a 0.0414-unit rise in CO_2 emissions. The coefficient for NRR is 0.0903, suggesting that a one-unit increase in natural resource rent leads to a 0.0903-unit surge in CO_2 emissions. The coefficient for FDI is −0.124, implying that a one-unit increase in foreign direct investment leads to a decrease of 0.124 units in CO_2 emissions. The coefficient for TO is 0.0299, indicating that a one-unit increase in trade openness leads to a 0.0299-unit rise in CO_2 emissions, holding other factors constant. The coefficient for UR is 0.0354, implying that a one-unit increase in urbanization results in a 0.0354-unit surge in CO_2 emissions.

For AMG, holding other variables constant, the coefficient for technological innovation is 0.0291. This signifies that for every one-unit increase in trade intensity, there is a 0.0291-unit increase in CO_2 emissions; the coefficient for REC is 0.0949. This means that a one-unit increase in renewable energy consumption leads to a 0.0949-unit increase in CO_2 emissions. The coefficient for FI is 0.0712. This implies that for every one-unit increase in financial innovation, there is a 0.0712-unit increase in CO_2 emissions. The coefficient for NRR is 0.103. This suggests that a one-unit increase in natural resource rent results in a 0.103-unit increase in CO_2 emissions. The coefficient for FDI is −0.1738. This denotes that a one-unit increase in foreign direct investment leads to a drop of 0.1738 in CO_2 emissions. The coefficient for TO is 0.1146. This suggests that for every one-unit increase in trade openness, there is a 0.1146-unit increase in CO_2 emissions. The coefficient is 0.0949. This indicates that a one-unit increase in urbanization results in a 0.0949-unit increase in CO_2 emissions. The coefficient c is 2.9894. This represents the baseline level of CO_2 emissions when all independent variables are zero.

The coefficient for TI is 0.1332, with a standard error of 0.0031 and a t-statistic of 42.9677. This indicates that a one-unit increase in technological innovation directs to a 0.1332-unit rise in CO_2 emissions. The coefficient for REC is 0.1075 with a standard error of 0.0049 and a t-statistic of 21.9387. This suggests that a one-unit increase in renewable energy consumption results in a 0.1075-unit rise in CO_2 emissions. The coefficient for FI is 0.0776, with a standard error of 0.0058 and a t-statistic of 13.3793. This implies that there is a 0.0776-unit increase in CO_2 emissions for every one-unit increase in financial innovation.

For CS-ARDL, holding other variables constant the coefficient for NRR is 0.0523, with a standard error of 0.007 and a t-statistic of 7.4714. This suggests that a one-unit increase in natural resource rent results in a 0.0523-unit rise in CO_2 emissions. The coefficient for FDI is −0.0477 with a standard error of 0.0022 and a t-statistic of −21.6818. This indicates that a one-unit increase in foreign direct investment leads to a decrease of 0.0477 units in CO_2 emissions. The coefficient for TO is 0.1373, with a standard error of 0.004 and a t-statistic of 34.325. This suggests that for every one-unit increase in trade openness, there is a 0.1373-unit increase in CO_2 emissions. The coefficient for UR is 0.1425 with a standard error of 0.0035 and a t-statistic of 40.7142. This implies that a one-unit increase in urbanization results in a 0.1425-unit rise in CO_2 emissions. The coefficient is 7.6675 with a standard error of 0.2329 and a t-statistic of 32.9218. This represents the baseline level of CO_2 emissions when all independent variables are zero.

The coefficient (see Table 6) estimates represent the expected change in the dependent variable for a one-unit increase in the respective independent variable, holding other variables constant.

For instance, a coefficient of 0.0925 for EX implies that a one-unit increase in EX is associated with a 0.0925-unit increase in the dependent variable. The standard errors reflect the precision of the coefficient estimates, with lower values indicating more precise estimates. The t-statistics assess the significance of the coefficient estimates, with higher absolute values suggesting greater significance. All coefficients have t-statistics with absolute values exceeding 2, indicating statistical significance. Further, the Anderson Canonical Correlation LM Statistics and Cragg-Donald (1993) F Statistics assess the IV estimation method's overall validity and model fit. Higher values of these statistics reveal better model fit and more robust instrument relevance, which is paramount for the IV estimates' reliability. Likewise, the Stock-Yogo Weak ID Test Critical Values serve as a benchmark to evaluate the strength of the instrumental variables. If the test statistic exceeds this critical value, it suggests a weak correlation between the instrumental variables and the endogenous regressors, potentially indicating issues with instrument relevance.

5. DISCUSSION OF STUDY FINDINGS

Our findings resonate with prior research showing a connection between higher export earnings and increased carbon emissions (Simas et al., 2015; Wang et al., 2019; Nguyen, 2022; Simas et al., 2015). Past studies have demonstrated a clear relationship between economic growth fueled by exports and rising levels of carbon emissions. This link is due to the energy-intensive operations of industries focused on exports, which result in more significant emissions due to the increased production and transportation requirements Hu et al. (2019). Our research confirms these findings, indicating that export earnings play a role in carbon emissions, as increased economic activity typically leads to greater energy consumption and environmental impact (Raihan and Tuspekova, 2022; Meyfroidt and Lambin, 2011). Countries with export-oriented economies are typically connected to worldwide supply chains that require the movement of raw materials, intermediate products, and finished goods over extensive distances. The logistics and transportation operations linked to international trade significantly generate carbon emissions, mainly from maritime shipping, air freight, and road transportation Anderson (2022). Furthermore, these economies are highly interconnected with global supply chains, which causes a rise in emissions from transportation and logistics operations (Ghadge et al., 2020; Li et al., 2023). Moreover, the growth driven by exports leads to increased energy consumption and emissions. Additionally, the reliance on fossil fuels for energy worsens emissions, along with the significant infrastructure development needed to facilitate export operations. The slow adoption of cleaner technologies also plays a role in emissions Mac Kinnon et al. (2018). However, some studies have reported conflicting results, showing either a negative or insignificant connection between export earnings and carbon emissions. For instance, (Elkins and Baker, 2001; Wang and Wang, 2020; Green, 2021; Huisingh et al., 2015) have noted situations in which economic growth driven by exports has decreased carbon emissions because of a transition to cleaner production methods and energy sources. Factors like trade openness, environmental laws, and technological progress are significant in determining the environmental impact of export-driven activities. The differences in research outcomes can be linked to the unique circumstances of these factors and variations in data analysis and modeling methods. Consistently, our research shows a positive link between export earnings and carbon emissions, which aligns with previous studies (Meyfroidt and Lambin, 2011; Anderson, 2022; Li et al., 2024). Various factors can explain this connection. Export-focused economies prioritize industries like manufacturing and resource extraction, which have high carbon footprints, leading to increased emissions. These economies also rely on extensive transportation and logistics networks due to their integration into global supply chains, further contributing to emissions. Economic growth driven by exports leads to higher energy consumption, mainly from fossil fuels, worsening emissions. Additionally, developing export infrastructure and energy-intensive activities adds to environmental pressures. Moreover, technological advancements may only sometimes prioritize sustainability, causing a delay in adopting cleaner technologies Ali et al. (2023). Our findings highlight the significant impact of export-driven economic models on carbon emissions, emphasizing the need for urgent implementation of sustainable development strategies to mitigate the environmental effects and address climate change effectively.

Our findings indicate a significant positive link between remittance inflows and zero carbon emissions, consistent with previous research. Various studies have observed similar patterns, attributing them to different factors. Recipients often use remittance funds to enhance their quality of life, leading to increased consumption of energy-intensive goods and services, thus raising carbon emissions (Ramakrishnan et al., 2020; Liu et al., 2023; Zaman et al., 2013). Additionally, remittances contribute to economic growth in recipient countries, promoting industrial activities and urbanization, which typically result in higher emissions. Moreover, remittances may support investment in carbon-intensive sectors like construction and transportation infrastructure, worsening emissions Hamouri (2020). Furthermore, depending on remittances as a reliable income source may hinder efforts toward sustainable development, as immediate economic priorities might overshadow environmental concerns Skjærpe (2021). It is essential to recognize differing results in research. Notwithstanding, some studies indicate a negative link between remittances and reduced carbon emissions by (Zhang et al., 2022; Dash et al., 2024; Zhang et al., 2023). Higher household incomes from remittances could result in investments in cleaner technologies or lifestyle changes that decrease energy use Rani et al. (2023). Remittances also finance renewable energy initiatives or conservation programs in recipient nations, helping to lower carbon emissions Hamouri (2020). Furthermore, the effect of remittances on emissions could differ based on the makeup of the receiving economy, how remittances are used, and policies aimed at encouraging sustainable development Ahmad et al. (2022). In addition to the mentioned factors, the correlation between remittance inflows and zero carbon emissions can also be explained by the potential absence of environmental regulations in countries receiving remittances. Without strict environmental policies, economic activities supported by remittances may not prioritize environmental sustainability, resulting in increased carbon emissions Li and Yang (2023). Additionally, remittance inflows could enable recipients to adopt carbon-intensive technologies or lifestyles with greater purchasing power, strengthening the link between remittances and carbon emissions Li and Yang (2023).

The research findings indicate a significant positive relationship between effective governance and the reduction of carbon emissions, aligning with existing literature (Abid et al., 2021; Kumar and Kumar, 2023; Chen et al., 2023; Zheng et al., 2024). Previous studies have emphasized the crucial impact of governance frameworks on environmental results. Good governance, which includes transparency, accountability, and solid regulatory structures, is recognized for promoting sustainable development. Evidence consistently demonstrates that nations with solid governance systems typically have lower carbon emissions due to stricter environmental policies, enforcement, and backing for renewable energy projects. Additionally, transparent decision-making processes encourage public involvement and supervision, leading to the implementation of environmentally friendly policies and behaviors (Hale et al., 2022; Hepburn et al., 2021). But, there are some findings which have contradictory findings (Ran et al., 2020; Sun and Huang, 2020; Napp et al., 2014). The effectiveness of governance mechanisms can differ significantly among countries due to historical, cultural, and institutional factors. Some nations excel in governance, while others face challenges like corruption and political instability, impacting environmental management Thelma et al. (2024) Varied priorities among policymakers, economic interests, and stakeholders can influence how environmental policies are carried out, resulting in different results Urban et al. (2011). External factors such as global economic trends, technology advancements, and international agreements can also affect a country's ability to shift towards low-carbon pathways, regardless of governance quality Erdogan et al. (2023). Good governance is beneficial in decreasing carbon emissions, but its effectiveness can be influenced by various factors such as economic structure, technological readiness, and social norms Ambrosio-Albala et al. (2023). Although the study confirms the significance of good governance in advancing zero carbon emissions, further investigation is needed to understand the complex interactions that influence environmental results. This will help in developing more successful policy measures and sustainability plans.

Our study's results align with previous research, supporting a positive link between innovation and achieving zero carbon emissions (Li and Wang, 2017; Gu et al., 2019; Khan et al., 2020a and Hussain et al., 2022). Various studies have indicated that innovation, especially in clean energy technologies and sustainable practices, is crucial for reducing carbon emissions by improving energy efficiency, resource use, and adopting renewable energy (Li and Wang, 2017; Dominković et al., 2018). These findings reinforce the idea that technological innovation is essential for promoting environmental sustainability. Nevertheless, it is essential to recognize that specific research has shown conflicting or uncertain results on how innovation affects carbon emissions Fontaras et al. (2017). These discrepancies can be attributed to differences in research methods, variations in innovation policies and practices across regions, and economic development Mohideen et al. (2023). For example, while innovation can result in cleaner technologies and processes in more advanced economies, the impact may be less significant in less developed areas with restricted access to technology and expertise Omri (2020). Moreover, regulatory frameworks, market incentives, and institutional support for research and development influence the impact of innovation on reducing carbon emissions Hassan et al. (2023). Sometimes, innovation can result in rebound effects, where efficiency improvements are negated by higher consumption or production levels, hindering emission reduction efforts Font Vivanco et al. (2022). Despite this, research emphasizes promoting innovation as a critical element in achieving zero carbon emissions Wang et al. (2022). Policymakers can drive this by investing in research, encouraging technological progress, and facilitating partnerships between public and private sectors to expedite the shift towards a sustainable, low-carbon future Pigato et al. (2020).

Our research emphasizes the significance of considering policy measures and technological advancements to reduce the environmental effects of economies that rely on exports. Although export revenues are crucial for economic progress, policymakers must focus on sustainable development approaches that separate economic expansion from environmental harm. By enforcing strict environmental policies, encouraging the use of eco-friendly technologies, and supporting the adoption of renewable energy sources, a more sustainable path for export-driven growth can be achieved. Moreover, it promotes collaboration among nations and shares expertise on sustainable economy.

6. CONCLUSION AND POLICY SUGGESTION

Our research has provided significant findings on the intricate connection between different socio-economic factors and achieving zero carbon emissions in Sub-Saharan African nations. By conducting a thorough empirical analysis, the study investigated the correlations between export earnings, remittance inflows, innovation, governance quality, clean energy utilization, and carbon neutrality from 2001 to 2020. The results emphasize the importance of export earnings and remittance inflows in impacting carbon emissions, indicating the necessity for sustainable development approaches that harmonize economic growth and environmental conservation. The significant factors influencing carbon emissions in the region include export earnings, remittances, good governance, clean energy, and innovation. These results emphasize the interrelation between economic activities, governance systems, technological advancements, and environmental outcomes. The correlation between export earnings and carbon emissions implies that economic growth from export-focused industries can result in higher carbon emissions. Likewise, despite aiding economic development, remittances can also contribute to increased carbon emissions. The correlation between export earnings and carbon emissions implies that economic growth from export-focused industries can result in higher carbon emissions. Likewise, despite aiding economic development, remittances can also contribute to increased carbon emissions. Conversely, effective governance practices, which include transparency, accountability, and robust regulatory systems, are linked to lower carbon emissions. This highlights the crucial role of good governance in advancing sustainable development and reducing environmental harm. The use of clean energy technologies and investment in innovation are linked to lower carbon emissions, suggesting they can help reduce carbon levels in the area. This highlights the significance of shifting to renewable energy sources and promoting innovation ecosystems to reach carbon neutrality targets. The research results are consistent with previous studies, but the study's constraints, such as limited data and possible endogeneity problems, are recognized. To delve deeper into these connections, future studies could use more extensive data sets and advanced statistical methods to understand better the factors influencing Sub-Saharan Africa's carbon emissions. The research adds to the increasing understanding of sustainable development and offers essential insights for decision-makers. It emphasizes the significance of comprehensive approaches considering economic, social, and environmental aspects to attain a sustainable, environmentally friendly future in Sub-Saharan Africa and other regions.

The policy recommendations aim to provide feasible and practical measures for Sub-Saharan African nations to achieve carbon neutrality and promote sustainable development.

One essential suggestion is to prioritize investment in renewable energy infrastructure, which offers immediate advantages by diversifying energy sources and decreasing reliance on fossil fuels. This strategy helps reduce greenhouse gas emissions, improves energy security, and strengthens resilience against external factors like oil price fluctuations or supply interruptions. Secondly, promoting innovation and technology transfer is crucial to support sustainable development. Governments can encourage the uptake of green technologies and practices to boost economic growth, generate employment, and enhance productivity in critical industries. Furthermore, fostering innovation can create customized solutions to environmental issues, catering to the unique requirements and goals of individual nations. Next, improving governance and regulatory structures is a viable strategy for promoting carbon neutrality and sustainable development. Governments can achieve this by bolstering institutions, enforcing environmental laws, and ensuring effective policy implementation. Transparent and accountable governance practices foster trust among stakeholders, enabling cooperation and partnerships for sustainable development projects. Next, offering incentives like tax breaks, subsidies, or grants effectively motivates businesses and individuals to embrace eco-friendly practices. Governments can help offset the upfront expenses of adopting clean technologies and encourage implementing sustainable behaviors, such as energy efficiency and waste reduction. These incentives prompt immediate action and promote enduring shifts in behavior, resulting in sustained environmental advantages. Investing in education and capacity-building initiatives is crucial for increasing awareness about climate change and sustainable development. Empowering individuals with knowledge and skills enables governments to create a skilled workforce to drive innovation, adopt sustainable practices, and effectively address environmental issues. Education is also essential for shaping public attitudes and behaviors and promoting environmental stewardship and accountability. Finally, international collaboration and partnerships allow Sub-Saharan African countries to access funding, technology, and expertise for sustainable development projects. Engaging with international organizations, donor agencies, and stakeholders allows these countries to utilize resources and knowledge from global initiatives, aiding in advancing carbon neutrality. Additionally, collaboration enables knowledge exchange and learning, enabling countries to adopt best practices and learn from the experiences of others dealing with similar issues.

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