SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 5, (2026), pp. 2204-2223
Open Access. Online & Print

DOI: 10.5281/zenodo.21377848

ASSESSING THE CONTRIBUTION OF GREEN INVESTMENT TO INDUSTRIAL DECARBONIZATION IN SUB-SAHARAN AFRICA: THE RENEWABLE ENERGY PERSPECTIVE

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Received: 20/04/2026
Accepted: 05/05/2026

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ABSTRACT

The largely untapped question of whether green investment can decarbonize industries in sub-Saharan Africa is the driving force behind this study, considering the region is increasingly emitting carbon emissions and is in dire need of development. The paper will analyze how green investment will affect the carbon emission of industries in 42 sub-Saharan African countries between the year 2001 and 2024. The results of the study using pooled mean group estimation, two-stage least squares, fully modified ordinary least squares, heterogeneous Driscoll-Kraay estimations, and Dumitrescu-Hurlin panel causality tests, all show that green investment, proxied by renewable energy investment, has a significant negative impact on industrial carbon emissions at the aggregate level. Green investment and emissions have a bidirectional causality, which is partially counterbalanced by carbon-intensive access to electricity. It is also important to note that green investment has counterintuitive emissions-increasing impacts in low-income countries, highlighting the significance of income-differentiated policy frameworks. Before ramping up investment programmes in lower-income economies, policymakers should prioritize the absorptive capacity building, through technology transfer, green industrial policy and workforce development. The growth of energy infrastructure should be based on clean energy transitions, and the regional coordination mechanisms should be used to harmonize the green finance standards. The institutional reform should be seen as a co-investment with climate finance in order to maximize decarbonization multipliers across income groups.

KEYWORDS: Green Investment, Industrial Decarbonization, Carbon Emissions, Sub-Saharan Africa, Regulatory Quality.

JEL Codes: F21, L60 O55, Q54, Q43,

1. INTRODUTION

With the world's industrialization on the rise, one of the key issues of the current climate policy debates has been the decarbonization of industry. This concern is coming from the fact that global total energy combustion and industrial carbon emissions are estimated to be 37.3 $GtCO_2$, making the policy attention and investment in industrial decarbonization a justified course (International Energy Agency, 2024). Industrial decarbonization is a well-known concept used when talking about achieving carbon neutrality and sustainable development and means the process of gradual reduction of carbon emissions associated with industrial processes (Zimmer & Hoffmann, 2023; Khan et al., 2021; Daniya & Tang, 2024). The multi-source nature of the sector, besides the energy intensive processes and direct emissions at the process level, are some of the notable factors that contribute to emission burden of the industrial sector. Importantly, the global GHG emissions are highly concentrated in heavy industry, mostly because the existing production systems are capital intensive as well as the existing industrial technologies with high structural inertia (Climate Policy Initiative, 2024; Phoumin et al., 2025). But without reconfiguration of the financial architecture that determines the direction of industrial investment decisions and an industrial structural change not bias towards carbon-intensive production.

In this global emissions scenario, Sub-Saharan Africa (SSA) is a region of concern with special structural complexity. The World Development Indicators (WDI, 2024) revealed that South Africa's industrial carbon emissions (which includes industrial combustion in the energy sector, direct industrial processes and the power sector) have South Africa leading the pack as the highest industrial emitter in the sub-region, emitting more than 220 million tons of CO_2 equivalent from 2000 to 2023. Many of the economies in Sub-Saharan Africa (SSA) are less industrial but the development path in the sub-region indicates that industrial carbon emissions are virtually guaranteed to increase as economies seek to become more industrialized. For the sectors, the key emitters are energy and resource-based sectors, such as the petrochemicals, coal mining, chemical and iron and steel sectors, but sadly these sectors form the backbone of manufacturing and exports in the sub-region (Goga & Bell, 2024). Again, they are generally capital-intensive industries, and are often considered one of the most difficult sectors to decarbonize (Goga & Bell, 2024; Climate Policy Initiative, 2024; Phoumin et al., 2025). Carbon lock-in in Sub-Saharan Africa is especially problematic, as it is often difficult to move away from fossil fuel based industrial pathways, with energy demand increasing, even with green investment policy environment, the fossil fuel intensive industries are increasingly locking out the transition towards lower carbon industrial pathways (Steed et al., 2025; Ogaya et al., 2024).

One of the potential transformative mechanisms, green investment, has been encouraged through the instruments of green finance and these have been designed and evolved accordingly. Renewable energy is one of the green finance products which can be used to promote and boost green projects. Green investments, particularly renewable energy are found to attract long-term capital and thus can contribute to tangible carbon emission reduction in line with the literature (Al Mamun et al., 2022; Jin et al., 2023; Jiang et al., 2025). The evidence from Sub-Saharan Africa is consistent with the above linkage, as Abdi et al. (2025) and Amoah et al. (2024) demonstrated that renewables investments have positive impacts on the environment despite the prevailing industrialization and urbanization trends and recommended integration of clean energy investments with industrial policy. On the international level, Khan et al. (2021) conclude that the carbon intensity of industry has significantly decreased with the introduction of hybrid solar-wind energy systems, Daniya and Tang (2024) estimate that the Green Economy Policy of Kazakhstan has reduced carbon emissions of industry by about 8% with energy transition measures, and Zimmer and Hoffmann (2023) estimate that the carbon emissions of industry will be reduced by 92% in Europe by 2050 with green investment in electrification, energy efficiency and carbon capture and hydrogen. All this evidence points towards investments in renewables being an enabler of industrial decarbonization, and a structural enabler of long-term industrial upgrading and competitiveness.

Despite the proven potentials of green investment and an effective mechanism for decarbonization, the geographical dispersion and institutional imbalances in Sub-Saharan Africa have affected its progress in the sub-region. In the first instance, only few of the countries in sub-Saharan Africa have specific decarbonization plans. According to the Industrial Decarbonization (2024), kenya was only the first country come up with first industrial decarbonization roadmap (Industrial Decarbonization, 2024). This is followed by the Just Energy Transition Investment Plan developed in

South Africa to transition industrial energy use from fossil fuels to renewables, including the potential for the use of green hydrogen in agro-processing industries to reduce carbon intensity (Steed et al., 2025). In Uganda, bioenergy in the sugar industry is being utilized in industrial processes and this has led to a significant reduction in the use of fossil fuels (International Renewable Energy Agency, 2024).

However, the size and pace of these programmes are still far from what is needed to meet the sub-region's climate challenge. Carbon emissions from industries are significant considering that the industrial sector contributes approximately 16.8% of the sub-regional fossil fuel-induced GHGs (Mwesiga & Lyakurwa, 2025), and renewable energy investments have a huge potential to decarbonize as much as 73% of total GHGs (Acheampong, 2021). Countries with rich energy resources, such as coal dependent countries, are experiencing a diminishing energy resource base, increasing marginal cost of energy production and a loss of industrial and trade competitiveness (Steed et al., 2025). Part of the reason for this lack of progress is that climate capital is being misallocated, with less than USD 13 billion of the USD 100 billion promised for climate finance going towards renewable energy between 2010 and 2018, compared with more than USD 70 billion that was allocated to fossil fuels (Chiyemura et al., 2021). This will further worsen the industrial carbon lock-in problem and make the sub-region more susceptible to environmental risks of frequent droughts and floods, as well as to the loss of public health, inclusive growth and access to the increasing number of carbon constrained markets.

The number of studies on green investment, green finance and industrial carbon emissions has increased but there is still a small number of empirical studies on the nexus of these three in the context of Sub-Saharan Africa. Prior studies have concentrated on individual aspects of this link and have been unable to provide a sectoral perspective on the potential green investment can have in the process of industrial decarbonization. Abdi et al. (2025) and Adamson et al. (2024) analyzed the green investment's contribution to the environmental quality and overall carbon emissions, respectively, without breaking down the analysis to the industrial sector level. Al Mamun et al. (2022) and Reitsema and Scholtens (2025) revealed a positive relationship between the investment in green projects and firm performance and competitiveness, and Lee et al. (2023) and Lin et al. (2023) indicated that the Chinese renewable energy investment led to industrial upgrading and capacity expansion. More recently, Jiang et al. (2025) and Le Thanh (2025) have suggested that the effects of green FDI are higher with respect to value added. None of the contributions however provides an empirical analysis specifically in the context of the industrial decarbonization challenge in Sub-Saharan Africa and none of the studies outlines the pathways of how green investment can contribute to reducing industrial carbon emissions in the sub-region. This is a scientific gap, but also a policy constraint, especially for the sub-region, where recommendations on the use of green capital for the decarbonization of the industrial base are much needed.

To this end, this paper aims to investigate the contribution of green investment in the industrial decarbonization process in Sub-Saharan Africa (SSA) with a particular emphasis on non-hydro renewable energy investments. Not including hydropower is because the study focuses on the incremental decarbonization effects of private renewables investments, which are commercially oriented so that the true nature of private green investment dynamics in the sub-region can be captured. This study has three original and scholarly contributions. First, it fills an empirical gap by studying the relationship between green investment and industrial decarbonization, in Sub-Saharan Africa, in an analytical panel-level study. Second, it brings renewable side of green investment and the carbon emission of the industrial sector into the spotlight and provides granular and sector-specific data on the potential for targeted investments for decarbonization in hard-to-abate industrial sector. Third, the study's results offer an evidence-based perspective to African policymakers and industrial investors on the benefits of channeling green capital for the ultimate decarbonization of the industrial sector and so facilitate the structural carbon lock-in challenge and sustainable industrial development in the sub-region.

The remainder of the paper will have the following structure. Section 2 expounds on the conceptual and empirical literature review. Section 3 demonstrates the methodology which informs about the sources of data and paradigm applied in the methodology. Section 4 talks about and gives the empirical findings. Section 5 concludes by giving policy implications and the research directions in the future.

2. LITERATURE REVIEW

The theoretical foundation for the study on the role of green investment in industrial decarbonization in Sub-Saharan Africa can be based on various interrelated theories that focus on the relationship between finance, technological innovation and environmental sustainability. Theories such as the pollution halo hypothesis and the pollution-haven hypothesis, that is highly associated with foreign direct investment (FDI), was highlighted by researchers like Abdi et al (2025) and Le Thanh (2025). The theories provide valuable insight into the environmentally friendly practices and clean technologies that can be transferred to sub-Saharan African countries, or a situation where polluting industries move into countries that have weaker environmental regulations (Le Thanh, 2025). The halo effect hypothesis provides anther valuable insight into the transfer of green investment for industrialization via FDI from more advanced energy-efficient countries in the case of sub-Saharan African countries where regulatory and institutional quality is a challenge (Adamson et al., 2024; Le Thanh, 2025).

Another group of supporting theories are the environmental and economic interaction models. Adamson et al. (2024) emphasized the double dividend hypothesis which states that good environmental regulation could also lead to growth as it helps to minimizing ecological degradation. Also, Muchiri et al. (2025) and Lwesya (2025) used the Environmental Kuznets Curve (EKC) to describe the complex dynamic between development and emissions. These are especially relevant in Africa, as the continent is still in the process of industrialization and there could be a period of time when emissions increase, but with investments in green technologies, emissions can be reversed in the medium to long-term. But, as Sonnenschein and Mundaca (2016) pointed out, there is a need to empirically validate optimism about "win-win" green growth, and therefore, while the EKC and double dividend hypothesis, etc., are valuable theories in their own right, they are insufficient.

A better explanation as to the role that green investment plays in industrial decarbonization comes from the Ecological Modernization Theory (EMT). Drawing on the EMT, Jiang et al. (2025) proposed that technological advancements and financial assistance can balance economic development and environmental protection. Therefore, EMT has been emphasized to show the importance of green finance and green investment to stimulate the capital flow to renewable energy and low carbon technology to transform the industrial structure and decarbonization process. This is especially suitable for Sub-Saharan Africa, where industrial activities are heavily dependent on carbon-based sources of energy, and where structural reforms, such as electrification and renewable energy development, are urgently required in order to unlock productivity gains, while reducing emissions (Cai et al., 2024).

Building on the idea of the EMT, other theories like green growth theory (Mehmood & Kamal, 2025) and stakeholder theory (Lwesya, 2025) have also enhanced the importance of green investment for achieving environmental protection and inclusive economic development goals, which includes people, firms and governments. These are ideas that are similar to what is going on in sub-Saharan Africa today: Industrial decarbonization is not only a funding issue, but a stakeholders' issue as well. Although the different theories could have been able to explain the role of green investments in industrial decarbonization to some extent, the EMT is considered the most suitable theory to evaluate the decarbonization role of green investments in sub-Saharan Africa. It is an integration of the economic, technological and financial aspects of decarbonization and adapts to the realities of the industrial development of Sub-Saharan Africa. The specific approach of green investment for decarbonization in the region is through the lens of structural change, as green finance and technological innovation are the most relevant mediums to analyse the connection between industrial development, environmental quality and financial flows in the region.

2.1. Empirical Review

On the contribution of green investments to industrial decarbonization, there are appreciable number of related studies that share a similar bearing on the subject matter. In the first instance, green investments, through green finance instruments, are useful for the decarbonization process through carbon emissions. Al Mamun et al. (2022) demonstrated that green finance, particularly green bonds, had a significant negative effect on global CO_2 emissions in both developed credit markets and innovative economies. On another stand, Basturk (2024) revealed that a 1% increase in green finance is associated with a 0.012% reduction in global carbon emissions, thereby emphasizing how important they are to environmental protection. Reitsema and Scholtens (2025) added that the corporate green bond issuance lowered the emission of greenhouse gases and CO_2 intensity with a 3-year lag effect after the issuance. Moreover, Wu et al. (2024) revealed that green finance has a mediating effect on the relationship between carbon emissions efficiency and supportive role in Chinese cities, and Xiong et al. (2025) found that green finance has a negative effect on emission intensity through green investment and green bonds, but green equity was not significant. Zhu et al (2024) found that green finance enhanced the decarbonization of the energy consumption structure in China through green technology innovation and industrial development. Nabil et al. (2024) found in a study in Morocco that green finance contributes to environmental protection while maintaining a balance between renewable energy, decarbonization and economic growth.

There are some other strands of literature that departed from the direct impact of green investments on carbon phenomenon to considering the influential role of institutional and investment environments. Thanh Le (2025) showed that the quality of institutions had a moderating effect on the effectiveness of green finance on green FDI, which was negative in the short run but turned positive in the long run. Traore and Asongu (2024) studied the effects of green technology diffusion on CO2 emissions in 43 Sub-Saharan African countries and revealed that the quality of institutions enhanced the effects of the CO2 abatement potential of green technology in developing economies, highlighting the importance of good institutions for improving environmental performance. Lee et al. (2023) suggested that green finance has contributed to the economic growth promotion, industrial upgrading and transition to renewable energy, which has reduced carbon intensity in China. With 40 countries, Zhang et al. (2023) found that the decarbonization contribution of green energy is influenced by the financial structure. Yang (2025) found that policy understanding, socio-economic alignment and market mechanisms are the key factors that affect the effectiveness of green finance in China, India and Japan.

In more specific approach that concerns this study, some study are committed to the relationship between renewable energy, a significant project of green investment, and the process of industrialization and decarbonization. To this end, Abdi et al. (2025) discovered that the quality of the environment in 38 Sub-Saharan African countries was enhanced by renewable energy and digitalization, but degraded by economic growth, industrialization and urbanization. Amoah et al. (2024) showed that industrialization led to an increase in carbon emissions in Sub-Saharan Africa, where trade openness strengthened this relationship, requiring the imposition of stronger industrial regulations. This was followed by Amoah et al. (2025) who observed positive effects of renewable energy transitions on climate finance in 36 Sub-Saharan African countries, a positive sign of how zero-carbon policies can attract more investments. Mwesiga and Lyakurwa (2025) verified the negative impact industrialization had on climate outcomes in Sub-Saharan Africa and the need to adopt green industrial policies. Momodu et al. (2022) reported that the power sectors of Sub-Saharan Africa have made little progress towards decarbonization, and that political and economic alignment is required.

There are also some country-level studies that the progress in green investment projects. Cai et al. (2023) found that shifting China's new energy vehicle subsidies into charging infrastructure led to a significant decrease in carbon emissions, especially in cities around the central and southern regions. Lin et al. (2023) further showed that green finance in China resulted in low usage of coal-fired power and the increased use of renewable energy. The findings of Mohammed et al. (2025), on the other hand, revealed that green technology in China resulted in higher CO2 emissions, suggesting that China is still far from the turning point or the U-shape of the Kuznets curve. Jin et al. (2023) found that 38 countries of the Organization for Economic Cooperation and Development (OECD) demonstrated that green bonds and renewable energy could help to enhance carbon neutrality. For the E7 economies, Jiang et al. (2025) found that the impact of the interaction between green finance and renewable energy has been found to decrease CO2 emissions. Mehmood and Kamal (2025) found similar positive effects in Pakistan, albeit being limited by institutional and political limitations. Ming et al. (2025) found that there was a paradoxical relationship of climate finance in 74 developing countries, where CO2 emissions were found to increase with climate finance, suggesting inefficiencies.

2.2. Gap in Literature

Considering the literature on the subject, green finance, renewable energy transition and industrial carbon emissions, there is a need to empirically investigate SSA as a specific analytical context. The majority of the studies are performed in China, OECD countries and larger panels of developing countries, and very few of these studies are methodologically limited and rarely use industry as a unit of analysis, and are performed in SSA. While the work of Amoah et al. (2024), Mwesiga and Lyakurwa (2025), and Abdi et al. (2025) provides valuable regional insights, there is a lack of connection between green finance, industrial policy, and carbon outcomes in SSA, especially in the context of green investment as a means of industrial decarbonization. This study, therefore, seeks to address this gap by empirically analyzing the impact of green investment on industrial decarbonization dynamics in the SSA economies and offer context-specific evidence to a literature so far dominated by evidence from more financially developed regions whose structural conditions are very different from those of the SSA.

3. DATA AND METHODOLOGY

This paper analyzes the role of green investments in industrial decarbonization in 36 sub-Saharan African (SSA) economies between 2001 and 2024, resulting in an unbalanced panel of up to 864 country-year observations. The baseline empirical model is based on the empirical models of Traore and Asongu (2024), Abdi et al. (2025) and Amoah et al. (2024):

INDCEM_it=α_i+β_1 GINVWH_it+β_2 ELECT_it+β_3 IND_it+β_4 REG_it+ε_it

where INDCEM_it denotes industrial carbon emissions for country i at time t; GINVWH_it is green investment; ELECT_it captures electricity access; IND_it represent industrial activity, respectively, included to test for a potential Environmental Kuznets Curve (EKC) inflection along the industrialization trajectory; REG_it proxies regulatory quality as a measure of institutional capacity; α_i is the country-specific fixed effect absorbing time-invariant heterogeneity; and ε_it is the idiosyncratic error term. The inclusion of INDSQ_it follows evidence from Amoah et al. (2024), who document the need for stronger regulation to control emissions in developing economies.

Table 1: Variable Definition and Sources.

Variable	Code	Measurement/Definition	Sources
Industrial Carbon Emissions	INDCEM	CO_2 emissions from industrial sector (metric tons per country i at time t)	World Bank; IEA Database
Green Investment	GINVWH	Investment in renewable energy and environmental technologies (current US$ or as % of GDP)	World Bank; International Energy Agency
Electricity Access	ELECT	% of population with access to electricity	World Bank; International Energy Agency
Industrial Activity	IND	Industrial value added (% of GDP) to test Environmental Kuznets Curve (EKC) effects	World Bank World Development Indicators
Regulatory Quality	REG	Institutional capacity index measuring strength of regulatory frameworks; range: 0-100	World Bank Worldwide Governance Indicators

Note: INDCEM = Industrial Carbon Emissions; GINVWH = Green Investment; ELECT = Electricity Access; IND = Industrial Activity; INDSQ = Industrial Activity Squared; REG = Regulatory Quality. The inclusion of INDSQ follows evidence from Amoah et al. (2024), documenting stronger regulatory needs in developing economies.

The main variable of interest is green investment (GINVWH), as there is increasing evidence that green financial flows lower the carbon intensity (Al Mamun et al., 2022; Basturk, 2024; Xiong et al., 2025). Electricity access (ELECT) is included because energy infrastructure has an impact on the emission profile of industry, and expansion of electricity access to cleaner grid electricity can be a substitute for fossil fuel-intensive off-grid electricity generation, which is particularly relevant in SSA (Momodu et al., 2022; Abdi et al., 2025). To capture the level of the industrialization–emissions relationship, which has been found to be significant in SSA by Amoah et al. (2024) and Mwesiga and Lyakurwa (2025), the level of industrial activity (IND) are added together. The regulatory quality (REG) has been motivated by the evidence of Traore and Asongu (2024) and Thanh Le (2025) that in developing economies, the quality of institutions affects the carbon-abatement effectiveness of green finance and green technology diffusion, and that without taking into account regulatory quality, the estimates of green investment would be a combination of direct financial impact and indirect impact via regulatory quality.

3.2. Pre-estimation Analysis

Cross-Sectional Dependence Test

This study first formally tests for cross-sectional dependence (CSD) of the panel before the tests for panel unit roots and cointegration. The critical values of conventional first-generation panel unit root tests (e.g., Im–Pesaran–Shin) are based on the assumption of cross-sectional independence, and thus are inconsistent if CSD is ignored (Pesaran, 2021). Theoretically, CSD is expected, and in practice, it is found in SSA economies that are susceptible to similar climate-finance aid programs and commodity-based industrial structures as pointed out by Amoah et al. (2024) and Abdi et al. (2025).

Pesaran (2004) scaled CD test is applied which is unbiased in both large-N/large-T asymptotics:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \xrightarrow{d} N(0,1)$$

where $\hat{\rho}_{ij}$ is the sample correlation of residuals between units i and j.

If the null is rejected in this statistic, then it is concluded that pervasive CSD is present, and that second-generation cross-sectionally augmented panel procedures should be used in all subsequent analyses.

Panel Unit Root Tests - CIPS and CADF

CSD is committed to using second-generation unit root tests with unobserved common factors once they have been confirmed. The tests used in this study are the Cross-sectionally Augmented IPS (CIPS) and Cross-sectionally Augmented Dickey-Fuller (CADF) tests proposed by Pesaran (2007) which are size-correct under CSD by purging cross-sectional variation through the cross-sectional mean augmentation.

The CADF regression is for each unit i:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + d_0 \bar{y}_{t-1} + \sum_{j=0}^{p} d_j\, \Delta\bar{y}_{t-j} + \sum_{j=1}^{p} c_j\, \Delta y_{i,t-j} + e_{it}$$

where $\bar{y}_t = N^{-1}\sum_{i=1}^{N} y_{it}$ is the cross-sectional mean, and $\Delta\bar{y}_{t-j}$ are lagged differences of the cross-sectional mean. $CADF_i$ is the t-ratio of the estimate is the t-ratio of $\hat{\rho}_i$. The panel CIPS statistic is a combination of the individual CADF statistics:

$$CIPS(N,T) = N^{-1}\sum_{i=1}^{N} C\,ADF_i$$

The null hypothesis is that all the series are nonstationary, that is, that all the units have a unit root ($H_0\colon \rho_i = 0$ for all i), and the alternative hypothesis is that a fraction of units is stationary. Both tests are carried out with and without a deterministic trend. The CIPS and CADF tests overruled the first-generation tests (LLC, IPS, ADF-Fisher) as the first-generation tests become oversized in the presence of CSD.

Panel Cointegration Tests

After integrating all variables of order one (I(1)), three complementary panel cointegration tests with varying null hypotheses, panel sizes and assumptions regarding the degree of heterogeneity are used.

Pedroni (1999, 2004) Test

Pedroni's residual-based method is based on the assumption that there is a null hypothesis of no cointegration, which is tested by analysing the stationarity of the residuals of the long-run regression. It offers various intercepts and trend coefficients for each member:

$$\hat{e}_{it} = \hat{\delta}_i \hat{e}_{i,t-1} + \hat{u}_{it}$$

The null hypothesis is $H_0\colon \delta_i = 1$ (unit root in residuals, no cointegration). Between dimension statistics are particularly appealing in the case of heterogeneous panels, where they allow for heterogeneity in the parameters across countries, and are less sensitive to cross-country parameter heterogeneity (Pedroni, 2004).

Kao (1999) Test

The Kao test is an extension of the Engle–Granger two-step residual-based test to allow for homogeneous cointegrating vectors and fixed effects, which are both panel-specific. The ADF type statistic is equal to:

$$ADF = \frac{\hat{\delta} - 1}{SE(\hat{\delta})}$$

The Kao test is more stringent than Pedroni's, but it is a good robustness test under the assumption of a homogeneous panel. No cointegration is the null and rejection is a complementary evidence to the Pedroni's heterogeneous framework.

Westerlund (2005, 2007) Error-Correction-Based Test

Third, as a form of robustness, the study uses the error-correction tests that are structurally different from the residual-based tests, which rely on the non-stationarity of the residuals, but on the absence of an error-correction mechanism (ECM).

$$\Delta INDCEM_{it} = \alpha_i + \gamma_i\left(INDCEM_{i,t-1} - \boldsymbol{\beta}_i{}'\mathbf{X}_{i,t-1}\right) + \sum_{j=1}^{p_i}\theta_{ij}\,\Delta INDCEM_{i,t-j} + \sum_{j=-q_i}^{p_i}\delta_{ij}\,\Delta\mathbf{X}_{i,t-j} + e_{it}$$

where γ_i is the error-correction speed of adjustment; $H_0\colon \gamma_i = 0$ means that there is no cointegration. However, the Westerlund test can accommodate CSD via bootstrapped p-values, which is very desirable in this case, as the cross-sectional dependence in the panel is confirmed. The Pedroni-Kao-Westerlund procedure is a combination which can be used to avoid size distortions that occur when using either of the two procedures separately (Westerlund, 2005; 2007).

Slope Heterogeneity Test

Prior to choosing the long-run estimator, the study checks for slope heterogeneity with the Pesaran and Yamagata (2008) $\tilde{\Delta}$ and bias-adjusted $\tilde{\Delta}_{adj}$ statistics which test for homogeneity of the regression slope coefficients across the panel units. The test is based on a standardized version of Swamy's (1970) dispersion statistic:

$$\hat{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right), \quad \hat{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E(\tilde{z}_{it})}{\sqrt{Var(\tilde{z}_{it})}}\right)$$

where $\tilde{S} = \sum_{i=1}^{N}\left(\hat{\beta}_i - \hat{\beta}_{WFE}\right)'\frac{X_i{}'M_\tau X_i}{\hat{\sigma}_i^2}\left(\hat{\beta}_i - \hat{\beta}_{WFE}\right)$ is Swamy's statistic, $\hat{\beta}_{WFE}$ is the weighted fixed-effects pooled estimator, and M_τ is the within-group demeaning matrix. If the null hypothesis (slope homogeneity) is true, then both statistics are normally distributed. In other words, rejection of H_0 suggests that the different SSA economies have a large variation in institutional, economic and infrastructural features as documented by Traore and Asongu (2024) and Mwesiga and Lyakurwa (2025) and that pooled estimators that impose the equality restriction on slopes (e.g., fixed-effects OLS) are therefore empirically inappropriate, and that the use of heterogeneous or robust estimators is justified.

3.3 Long-Run Estimation

Pooled Mean Group (PMG)

The Pooled Mean Group (PMG) estimator of Pesaran, Shin and Smith (1999) is used as the main long-run estimator. PMG imposes the same long-run coefficients (homogeneity of long-run slopes) across countries but short-run dynamics, error-correction speeds and intercepts are allowed to freely vary across countries. The ARDL(p, q) panel error-correction representation is:

$$\Delta INDCEM_{it} = \phi_i\left(INDCEM_{i,t-1} - \boldsymbol{\theta}'\mathbf{X}_{it}\right) + \sum_{j=1}^{p-1}\lambda_{ij}\,\Delta INDCEM_{i,t-j} + \sum_{j=0}^{q-1}\boldsymbol{\delta}_{ij}{}'\Delta\mathbf{X}_{i,t-j} + \mu_i + \varepsilon_{it}$$

where $\phi_i < 0$ is the country-specific error-correction coefficient that represents the speed of adjustment to long-run equilibrium, and the constrained long-run coefficient vector $\boldsymbol{\theta}$ and the heterogeneous short-run dynamics $\boldsymbol{\delta}_{ij}$. This is especially relevant in the context of PMG as Al Mamun et al. (2022) and Lee et al. (2023) report that the long-run impact of green finance is similar across country groups despite the significant variation in short-run impacts.

Panel Two-Stage Least Squares (2SLS)

To deal with the potential endogeneity of green investment (GINVWH), which may be jointly determined with industrial emissions if low emissions economies attract more climate capital (Amoah et al., 2025; Ming et al., 2025), the study uses a Panel Two-Stage Least Squares (Panel 2SLS) estimator. The approach instruments $GINVWH_{it}$ with valid instruments that have both relevance (correlated with the endogenous regressor) and exclusion restrictions (uncorrelated with ε_it). The first step is to regress $GINVWH_{it}$ on the instruments and all the exogenous controls:

$$GINVWH_{it} = \pi_0 + \boldsymbol{\pi}_1{}'\mathbf{Z}_{it} + \boldsymbol{\pi}_2{}'\mathbf{X}_{it}^{exog} + \nu_{it}$$

The fitted values $\widehat{GINVWH}_{it}$ are then put into the structural equation (1). The Kleibergen–Paap underidentification test and the Cragg–Donald first-stage F-statistic (based on Stock–Yogo weak-instrument critical values) and the Hansen J-statistic for overidentification are used to test the validity of the instruments. To tackle the simultaneity bias that would otherwise affect the results of the effect of green investment on emission reduction, Panel 2SLS is used.

Feasible Generalized Least Squares (FGLS)

To make sure that the results are as efficient as possible in the presence of heteroskedasticity and serial correlation, which is likely to be present in unbalanced macro-panels of the sort used in this study, the study relies on the Feasible Generalized Least Squares (FGLS) estimator, as extended by Beck and Katz (1995). The regression in the previous section is OLS, but FGLS adjusts the regression to accommodate cross-sectional heteroskedasticity and autocorrelation structures that are different across the panels:

$$\hat{\beta}_{FGLS} = \left(X'\hat{\Omega}^{-1}X\right)^{-1}X'\hat{\Omega}^{-1}y$$

Where $\hat{\boldsymbol{\Omega}}$ the estimated variance-covariance matrix of panel-specific AR(1) disturbances and cross-panel heteroskedasticity. FGLS is particularly important when T is large relative to N (e.g., T=24 and N=36) and can be used to exploit the temporal structure of the data to allow efficient parameter recovery. It has been included together with PMG and Panel 2SLS to make sure that the long-run estimates reported are not sensitive to distributional misspecification for three methodologically different approaches.

Heterogeneous Robustness Analysis: Driscoll–Kraay Standard Errors

The spatial dependence, serial correlation and heteroskedasticity, which are all supported by the CSD tests, are all taken account of by adding the Driscoll and Kraay (1998) nonparametric covariance estimator to the long-run estimates. This method provides heteroskedasticity- and autocorrelation-consistent (HAC) standard errors which are also robust to cross-sectional dependence of unspecified form. The Driscoll–Kraay covariance estimator is:

$$\hat{V}_{DK}(\hat{\boldsymbol{\beta}}) = (\mathbf{X}'\mathbf{X})^{-1}\hat{\mathbf{S}}_T(\mathbf{X}'\mathbf{X})^{-1}$$

$$\hat{\mathbf{S}}_T = \hat{\boldsymbol{\Gamma}}_0 + \sum_{l=1}^{m(T)} \omega\,(l,m)\left(\hat{\boldsymbol{\Gamma}}_l + \hat{\boldsymbol{\Gamma}}_l'\right)$$

where $\hat{\boldsymbol{\Gamma}}_l = T^{-1}\sum_{t=l+1}^{T}\mathbf{h}_t\,\mathbf{h}_{t-l}'$, $\mathbf{h}_t = \sum_{i=1}^{N}\mathbf{x}_{it}\,\hat{e}_{it}$ is the cross-sectional sum of score contributions at time t, $\omega(l,m)$ is the Bartlett kernel weight, and $m(T) = \lfloor T^{1/4}\rfloor$ is the lag truncation parameter. Importantly, the consistency of $\hat{V}_{DK}$ does not depend on the smallness or fixity of the number of cross-section units N, and is valid for panels with pervasive spatial dependence (Driscoll & Kraay, 1998). Following the spirit of Traore and Asongu (2024) and Amoah et al. (2025) who find differential green finance–emissions nexus outcomes across SSA subregions, the Driscoll–Kraay estimator is used for the country income-group subsample and resource-dependence stratifications.

Panel Dumitrescu–Hurlin (D–H) Causality Test

The Dumitrescu and Hurlin (2012) panel causality test is used to test the causality between green investment and industrial carbon emissions, and the causality between the control variables and emissions. This is done because this procedure is more suitable than the traditional Granger causality tests which are valid under both cross-sectional independence and dependence and coherent with the confirmed CSD structure of the data. The test is carried out using the individual Wald statistics of a heterogeneous VAR(p) model estimated for each cross-section:

$$INDCEM_{it} = \alpha_i + \sum_{k=1}^{K}\gamma_i^{(k)}\,INDCEM_{i,t-k} + \sum_{k=1}^{K}\beta_i^{(k)}\,GINVWH_{i,t-k} + \varepsilon_{it}$$

The individual Wald statistic for the null that $GINVWH$ does not Granger-cause $INDCEM$ in unit i is $W_{i,T}^{HNC}$. Then the cross-sectional averages of the Dumitrescu–Hurlin $\bar{W}$ and standardized $\bar{Z}$ panel statistics are calculated:

$$\bar{W}_{N,T} = N^{-1}\sum_{i=1}^{N}W_{i,T}^{HNC}$$

$$\bar{Z}_{N,T} = \sqrt{N}\left(\frac{\bar{W}_{N,T} - K}{\sqrt{2K}}\right) \xrightarrow{d} N(0,1) \quad \text{as } N,T \to \infty$$

For finite samples, Dumitrescu and Hurlin (2012) provide an approximated $\tilde{Z}_{N,T}$ statistic with a t-distribution correction. The null hypothesis is **"homogeneous non-causality"** ($H_0: \beta_i^{(k)} = 0$ for all i and k), while the alternative is that Granger causality exists for at least one panel unit.

4. RESULTS AND ANALYSIS

The descriptive statistics in Table 2 offer some insight into the variation of the factors of industrial emissions and green investment among the sample. The mean of industrial carbon emission (INDCEM) is 2.15 with the highest possible emission being 61.10 and a standard deviation rate of 7.98 implying that few observations have a very high contribution to the emissions. This implies that the contribution of the majority of industries to the overall emission is relatively low but some high emitters might be contributing to wider environmental issues. The overall average of green investment (GINVWH) is 44.29, which shows a moderate level of commitment to environment-friendly activities, but the wide range (from zero to almost full-scale investment) indicates that there are drastic differences in the level of commitment to sustainability in various regions or companies.

The same applies to the access to electricity (ELECT): the mean is 40.24, but the range and variability describe the unequal development of infrastructures and this aspect could impact the development of industries relying on carbon-rich energy sources. These comments reflect the difficulty in tackling the problem of industrial emissions, where investment in green technologies and energy supply is very different from one situation to the next. The mean of the industrial activity (IND) is 25.57 but the range is quite large, indicating that some sectors are more intensive than others. This is also highlighted by the squared term of industrial activity (INDSQ), the extreme values of which imply the possible non-linear effects of the scale of industry on emissions. The regulatory quality (REG) with an average of 29.43 and a significant variation highlights the fact that institutional control varies significantly across the sample and potentially it may alleviate or increase the effect of the environment in line with the local governance performance.

Table 2: Descriptive Statistics.

Statistic	Observations	Mean	Maximum	Minimum	St. deviation
Indcem	863	2.150	61.100	0.000	7.980
Ginvwh	863	44.290	99.410	0.000	33.760
Elect	863	40.240	100.000	0.000	26.010
Ind	863	25.570	72.150	3.240	12.010
Indsq	863	797.720	5205.620	10.500	820.970
Reg	863	29.430	86.060	0.000	19.340

Note. INDCEM = industrial carbon emissions; GINVWH = green investment; ELECT = electricity access; IND = industrial activity; INDSQ = institutional quality dustrial activity squared; REG = regulatory quality. Values are rounded to two decimal places for presentation.

Table 3 correlation analysis provides valuable insights into the relationship between industrial carbon emission and green investment, access to electricity, industrial activity and quality of regulation. It is interesting to note that the industrial emission (INDCEM) and the green investment (GINVWH) are negatively correlated at -0.179 ($p < 0.01$) meaning that as the level of green investment increases, the emission decreases. This provides a preliminary indication that if resources are directed towards environmentally friendly projects, then it would be possible to reduce the carbon production by industry. However, electricity access, industrial activities and regulatory quality are all positively related to industrial carbon emissions, a situation that suggest the carbonization roles of these factors in sub-Saharan Africa. Further, the table results showed only industrial activities had positive correlation with green investment, showing that industrial activities in sub-Saharan Africa are validating the Ecological Modernization Theory (EMT) (Jiang et al., 2025).

Table 3: Correlation Analysis.

Variable	indcem	ginvwh	elect	ind	reg
Indcem	1				

Ginvwh	-0.179***	1			
Elect	0.307***	-0.205***	1		
Ind	0.005	0.240***	0.111**	1	
Reg	0.247***	-0.145***	0.462***	0.001	1

Note. N = 863. Values represent Pearson correlation coefficients rounded to three decimal places; Significance levels: p < .01 ***, p < .05 **, p < .1 *; Variable descriptions: indcem = industrial carbon emissions; ginvwh = green investment; elect = electricity access; ind = industrial activity; reg = regulatory quality.

The results of Table 4 provide a clue to the interdependence of the variables, as well as to their statistical properties which are of paramount importance for proper modelling. The results of the cross-sectional dependence (CSD) tests indicate that the variables of industrial carbon emission (INDCEM), green investment (GINVWH), access to electricity (ELECT) and regulatory quality (REG) are cross-sectionally dependent at 1 percent level in the sample. This demonstrates how systemic these aspects are, as changes or shocks in an area or a nation are likely to affect others. However, no high cross-sectional dependence of industrial activity (IND) is found, suggesting that the variation in industrial activity is mainly driven by local context-specific factors and not systemic processes. The panel unit root tests also give an insight on the time variation of these variables. Most of the variables have no conviction of stationarity, except for partial evidence foe industrial activities and industrial carbon emissions. However, all the variables, green investment, access to electricity, industrial activity, and quality of regulation, are non-stationary in levels but became convincingly stationary after the first difference (I(1)). This implies that the series are convincingly I(1) variables and integrated at order 1.

Table 4: Cross-sectional dependence (CSD) and panel unit root tests.

Variable	CSD	CADF I(0)	CIPS I(0)	CADF I(1)	CIPS I(1)	Decision
Indcem	48.614***	−1.799	−2.189**	−2.192***	−4.828***	I(0)/I(1)
Ginvwh	2.637***	−1.876	−1.624	−2.516***	−4.143***	I(1)
Elect	113.502***	1.060		−7.246***		I(1)
Ind	0.208	−1.400***	−1.902	−2.476***	−4.580***	I(0)/I(1)
Reg	64.202***	−1.598	−1.851	−3.091***	−5.137***	I(1)

Note. *= p < .10, ** = p < .05, *** = p < .01; CSD is for cross-sectional dependence test; CADF is for cross-sectional ADF tests, CIPS is for the Cross-sectional augmented Im–Pesaran–Shin tests (IPS); I(0) and I(1) are for integration at levels and first differences, respectively

Table 5 shows the panel cointegration tests, which provide strong evidence for the long-run and stable relationship between the industrial carbon emissions, green investment, electricity accessibility, industrial activity and regulatory quality. In all the test methods, including the Kao test, Pedroni test and Westerlund variance ratio test, all the statistics are highly significant at the level of 1% and always reject the null hypothesis that there is no cointegration. That is, the levels of the variables may be non-stationary, but they change in sync with time. That is, the long-term evolution of the emissions is related to the large economic, infrastructural and institutional factors considered in this study.

Table 5: Panel Cointegration Tests.

Test & Statistic	Kao test	Pedroni test	Westerlund test
Modified Dickey–Fuller	4.412***		
Dickey–Fuller	3.180***		
Augmented Dickey–Fuller	2.233***		
Unadjusted modified Dickey–Fuller	-15.245***		
Unadjusted Dickey–Fuller	-12.396***		
Modified Phillips–Perron		3.380***	

Phillips–Perron		-3.331***	
Augmented Dickey–Fuller		-3.091***	
Westerlund – Variance Ratio			3.905***
Note. *= p < .10, ** = p < .05, *** = p < .01.			

The results of the slope heterogeneity test in Table 6 clearly show that the impact of the explanatory variables on carbon emissions by industries varies across sub-Saharan African countries. Both the Delta (14.337, $p < 0.01$) and the adjusted Delta (16.559, $p < 0.01$) provide strong evidence to reject the null hypothesis of homogeneous slopes and indicate that the effect of such factors as green investment, access to electricity, industrial activity or quality of regulations can vary significantly across locations.

Table 6: Slope Heterogeneity tests.

Model Specification	Delta	Adj. Delta	Decision (5%)
Model	14.337***	16.559***	Reject H_0
Note. *= p < .10, ** = p < .05, *** = p < .01.			

5. RESULTS

The outcome of the estimation in Table 7 is a good proof of the role of green investment in decarbonizing the industrial sector. In all three models (2SLS, FMOLS and PMG) the effect of green investment is negative and statistically significant (-0.018, -0.029 and -0.005, respectively). This uniformity between the dynamic and static models, even though it may be endogenous and have long-term effects, is a good sign that green investment can be a powerful tool to reduce the carbon emissions of industries. Control variables: Electricity access is always positive, meaning that the use of electricity is greater when there is industrial activity, which results in higher emissions. The results for industrial activity are mixed; positive results in PMG and FMOLS and not significant in 2SLS, which may be due to the context of the technology adopted or efficiency. The effect of regulatory quality is also model-specific, with a weak negative effect in PMG, a positive effect in 2SLS and a slightly negative effect in FMOLS, suggesting the complex and context-dependent nature of this effect. The most consistent and strongest results, however, are clear: Green investment results in a reduction of emissions and access to electricity in general results in an increase of emissions.

Table 7: Estimations: PMG, 2SLS and FMOLS.

VARIABLES	PMG	2SLS	FMOLS
ginvwh	-0.018***	-0.029***	-0.005**
	(0.003)	(0.009)	(0.002)
elect	0.022***	0.068***	0.019***
	(0.002)	(0.017)	(0.002)
ind	0.026***	0.008	0.018***
	(0.006)	(0.016)	-0.006
reg	-0.004*	0.060**	0.007**
	(0.002)	(0.027)	-0.003
ec	-0.123***		
	(0.031)		
Δginvwh	0.008		
	(0.009)		
Δelect	-0.012		
	(0.023)		

Δind	-0.037		
	(0.054)		
Δreg	0.002		
	(0.002)		
Constant	0.937	-1.384*	-1.384*
	(0.877)	(0.745)	(0.745)
Observations	827	756	827
Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1			

Table 8 looks at the effect of green investment, based on income groups. The overall panel shows a large negative impact (-0.028, p<0.01), while the impact is positive in lower-income countries (0.009, p<0.01), possibly as a result of transition costs or the inability to adopt green technologies. The negative impacts are small for LMICs (-0.007, p < 0.01) but large for UMICs (-0.394, p < 0.01), suggesting that green investment can be more effective in reducing emissions in more developed industrial sectors. Control variables include electricity access, which generally increases emissions, and industrial activity and regulatory quality, which can either increase or decrease emissions depending on income, and therefore can either promote or deter green investment. This suggests that income-sensitive policies, coupled with improved governance, industrial efficiency, and energy management, are important.

Table 8: Heterogeneous Driscoll-Kraay estimations.

Variables	Full panel	Lower-income countries	Lower middle-income countries	Upper middle-income countries
Ginvwh	-0.028***	0.009***	-0.007***	-0.394***
	(0.008)	(0.001)	'(0.002)	(0.064)
Elect	0.069***	0.021***	0.0111***	0.064
	(0.011)	(0.002)	(0.002)	(0.066)
Ind	0.006	-0.007*	0.032***	-0.673***
	(0.022)	(0.004)	(0.004)	(0.140)
Reg	0.053***	-0.009***	0.008**	-0.366***
	(0.015)	(0.002)	(0.003)	(0.090)
constant	-1.084	-0.031	-0.381*	59.950***
	(0.798)	(0.115)	(0.224)	(11.500)
Observations	863	383	360	120
Number of groups	36	16	15	5
Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1				

Lastly, the Dumitrescu-Hurlin causality tests in Table 9 indicate a very dynamic and interdependent system. The results reveal that there is bi-directional causality between green investment and industrial emissions (ginvwh ↔ indcem), suggesting that there is a self-reinforcing mechanism through which green investment causes emissions reduction and emissions increase causes green investment. The drivers of green investment (elect → ginvwh) and industrial activity (elect → ind) are electricity access, while regulatory quality drives and is a response to industrial activity (reg ↔ ind) and electricity provision (reg → elect). There are also regulatory responses to industrial emissions (indcem → reg), which in turn demonstrates that environmental impacts can result in institutional change. All of this indicates a highly interdependent system of emissions, investments, infrastructure, industry and governance that continually influence one another. This shows the importance of coordinated strategies that can leverage these feedback loops to achieve sustainable carbon emission reductions from industry to achieve decarbonization.

Table 9: Dumitrescu-Hurlin Panel Causality Tests.

Null Hypothesis:	W-Stat.	Prob.	Decision
ginvwh ⇏ indcem	2.09***	0.001	ginvwh ↔ indcem
indcem ⇏ ginvwh	2.89***	0.000	
elect ⇏ indcem	3.90***	0.000	elect ↔ indcem
indcem ⇏ elect	2.64***	0.000	
ind ⇏ indcem	2.44***	0.000	ind ↔ indcem
indcem ⇏ ind	2.43***	0.000	
reg ⇏ indcem	1.01	0.712	indcem → reg
indcem ⇏ reg	2.36***	0.000	

Note: *** p<0.01, ** p<0.05, * p<0.1; ⇏ is for "does no homogenously cause"; → represent uni-directional causality; ↔ represent bi-directional causality

6. DISCUSSION

6.1. Green investments and industrial decarbonization

Table 7 indicates that there is a negative correlation between green investment and industrial carbon emission in all the estimations of PMG, 2SLS and FMOLS, and the correlation is statistically significant. The results of methodologies support the claim that green investment is a feasible way of decarbonizing industries in Sub-Saharan Africa. These results are consistent with the available empirical evidence on green finance and environmental sustainability. For instance, other research such as Al Mamun et al. (2022), Basturk (2024) and Reitsema and Scholtens (2025) also documents a significant emissions-cutting effect of green financial instruments, such as green bonds, in the short term and the long term. The current findings support these findings and can be applied to the Sub-Saharan African context, which is often overlooked in the global climate finance discussion. Additionally, the transmission channel of innovation, as it is evident in the works of Wu et al. (2024) and Zhu et al. (2024), also gives theory the prospective reason that negative coefficients were observed, and green investment probably boosts cleaner technologies and energy efficiency in the industrial process. This is an argument that financial flows towards environmentally friendly projects can lead to structural change towards the low-carbon industrial systems (Xiong et al., 2025; Nabil et al., 2024).

However, whilst there are general similarities in the findings with the rest of the world, there are some finer details that are apparent when the findings are considered in the context of the structural and institutional realities of Sub-Saharan Africa. There is empirical evidence specifically on the area that carbon emissions have been a problem in the area due to reliance on fossil fuels and lack of effective regulatory systems (Amoah et al., 2024; Mwesiga & Lyakurwa, 2025). In this regard, the inverse relationship between green investment and emissions found in this study is indicative of a gradual but important shift to the sustainable industrialization paradigm. This is also buttressed by Abdi et al. (2025), who point out the environmental advantage of the adoption of renewable energy and digitalization in the region. However, the relatively smaller coefficient of the FMOLS (-0.005) compared to PMG and 2SLS may be a sign of structural ineffectiveness, inadequate absorptive capacity, and delayed policy effects, which is also consistent with Momodu et al., (2022) who argue that the power sector makes slow progress towards decarbonization. Thus, it is not only possible to conclude that the results of the study are consistent with the literature but also to argue that the impact of green investment in Sub-Saharan Africa could be contingent on other complementary factors like institutions, technological readiness and regulation.

The introduction of supportive variables also helps to better understand the interaction between green investment and structural factors in affecting the process of industrial decarbonization. The positive and significant relationship between electricity access and emissions suggests that energy growth in Sub-Saharan Africa is still highly carbon-intensive, corroborating Momodu et al. (2022) and Ritchie (2023). This will therefore be somewhat offset by the increase in energy demand from the growth of industries as green investment will reduce emission. Similarly, the mixed results on industrial activity align with the mixed view of industrialization as highlighted in the literature in that it is linked to economic development, but in many instances, it is accompanied by increased environmental degradation if not green technologies are adopted (Amoah et al., 2024; Abdi et al., 2025). The mixed results of the regulatory quality also indicate the complexity of governance in the area, which aligns with the studies on the importance of institutional strength and policy coherence in the development of environmental performance (Yang, 2025). These control variables show that, while green investment is a key driver for decarbonization, it is primarily driven by energy structure, industrial dynamics and institutional effectiveness, and therefore, the need for a holistic and coordinated policy implementation in Sub-Saharan Africa.

6.2. Heterogeneous analysis of green investment and industrial decarbonization

The results of Table 8 confirm that green investment has a significant role in reducing the carbon emissions of industries, which is consistent with the literature which believes that green finance is among the potential pathways to decarbonization. This is also in agreement with the homogeneous PMG, 2SLS and FMOLS estimates for the full panel. The large and negative value of the coefficient of the full panel is consistent with empirical evidence that green financial instruments, especially green bonds and climate finance, lead to the reduction of emissions due to technological innovation, energy efficiency, and structural change (Al Mamun et al., 2022; Basturk, 2024; Reitsema & Scholtens, 2025). However, the results for the disaggregated income levels show some significant differences, confirming and uncovering theoretical and empirical expectations. The positive and significant effect of green investment in the lower-income countries, suggests that the initial phase of green transition may be accompanied by increasing emissions, which can be attributed to lack of efficiency, weak absorptive capacity or active industrial growth in the context of development. The result is in line with those who have found paradoxical/slow effects of climate finance in developing countries (Ming et al., 2025; Mohammed et al., 2025) and again with the environmental Kuznets curve hypothesis, where emissions rise at the initial stages and fall. On the other hand, the negative impacts are larger in low and upper-middle income countries, consistent with the thesis statement that the institutional quality, financial development and technological readiness improve the performance of green investments. The results from the developing economies and OECD countries also indicate that well-established financial framework and supportive policies have a better decarbonization effect of green finance (Jin et al., 2023; Jiang et al., 2025). The results are thus consistent with literature from more developed countries, but suggest the structural limitations of low-income Sub-Saharan African economies.

Importantly, these results reveal that the relationship between green investment and industrial decarbonization needs to be examined taking into account the heterogeneity of income levels. The differences in the coefficients of various income groups show that the notion of green investment is not uniform and depends on the economic development level, institutional capacity and maturity of an industry in a country. Weak institutional systems, low technological levels and carbon-intensive energy systems have been observed to be a challenge to the effectiveness of green investment in lower income countries (Yang, 2025; Alhassan et al., 2024; Mulugetta, 2023). On the other hand, the middle-income countries have a greater chance to leverage green finance due to their improved institutions and industrial structures, which foster the diffusion of green technologies and enhance environmental performance (Traore & Asongu, 2024; Abdi et al., 2025). It is this diversity that is proof that Sub-Saharan Africa does not have a single policy. Rather, the benefits of decarbonization of green investment should be maximized and country-specific solutions should be offered to facilitate sustainable industrial transformation in the region (Adamson et al., 2024; Amoah et al., 2025).

Panel Dumitrescu–Hurlin (D–H) Causality Test

The causality results shown in Table 9 indicate that there is a set of reinforcing causal links that clearly indicate the relationship between green investment and industrial decarbonization. The bidirectional causality (ginvwh ↔ indcem) supports that the green investment does not only affect the reduction of the carbon emissions but it is also affected by the growing carbon emissions, thus creating a feedback loop between the adaptive policy and market responses. This result is consistent with the prevailing literature that sets up a negative causal direction between green finance and emissions reduction via innovation, energy transition, and industrial upgrading (Al Mamun et al., 2022; Basturk, 2024; Reitsema & Scholtens, 2025; Wu et al., 2024; Zhu et al., 2024). Besides, industrial carbon emission also have bi-directional causality with electricity infrastructure growth and industrial activities. There are other causal relationships that are bi-directional causality with green investment, like industrial activity and quality of regulation, (ind ↔ reg; ind ↔ ginvwh). These relationships suggest that green investment is driven and supported by robust institutions and industrial systems, as confirmed by the positive impact of the quality of institutions and financial systems on the effectiveness of green finance (Traore & Asongu, 2024; Zhang et al., 2023; Yang, 2025). This is also corroborated by literature from the Sub-Saharan African context in which environmental pressures and policy responses can influence the sustainable investment and incremental decarbonization processes (Mulugetta, 2023; Ogaya et al., 2024; Adamson et al., 2024).

But there are other causal links to the results that reveal important tensions that can undermine or complicate the relationship between green investment and industrial decarbonization. The unidirectional causality between access to electricity (elect) and green investment (elect → ginvwh) and its powerful impact on industry (elect → ind) gives reason to think that the growth of energy infrastructure, which in Sub-Saharan Africa is usually based on fossil fuels, may indirectly drive up emissions and cancel out the payoff of green investment. This is in line with the carbon intensity of the energy and industrialization in the region (Amoah et al., 2024; Mwesiga & Lyakurwa, 2025; Momodu et al., 2022; Ritchie, 2023). Also, although emissions that lead to regulatory actions (indcem → reg) are conducive to adaptive governance, they can also indicate reactive, and not proactive, environmental management. This aligns with the literature which has pointed out the inefficiency and slow effect of climate finance in the developing countries (Ming et al., 2025; Mohammed et al., 2025).

7. CONCLUSION

This research was motivated by the question that remains important but not widely studied: does green investment lead to industrial decarbonization in sub-Saharan Africa? To address this question, 42 sub-Saharan African countries, covering data period from 2001 to 2024, were analyzed under multidimensional econometric frameworks. The results, using PMG, 2SLS, FMOLS, heterogeneous Driscoll-Kraay estimations, and Dumitrescu-Hurlin panel causality tests, are consistent with the hypothesis that green investment, which is represented by renewable energy investment, has a strong negative influence on industrial carbon emissions at the aggregate level, indicating a clear though slow structural adjustment toward sustainable industrialization in the area. Disaggregation by income level also contains some interesting insights; low-income nations paradoxically show early growth in emissions and green investment, as does high-income countries, which increasingly shows a strong decarbonization effect, which is consistent with early-stage transitional inefficiencies and with the environmental Kuznets curve, respectively. The bidirectional causality of the relationship between green investment and emissions substantiates a self-reinforcing feedback mechanism, albeit partial, compensation by carbon-intensive access to electricity. Taken together, these results suggest that, although green investment is a valid and quantifiable decarbonization tool that can be applied to sub-Saharan Africa, its success heavily depends on the background structural, institutional and energy-system factors, a fact that should form the basis of scholarly discussion and policy formulation in the area.

It is necessary to consider the limitations of the study to be able to situate the contributions of the study. Although its sample period (2001–2024) is quite lengthy, it can be argued that it might not adequately capture the rising pace of green finance mobilization in the post-2020 period in intensified global climate commitments, which underestimates the modern decarbonization potential of green investment. In greater detail, the proxy of green investment, renewable energy investment as a proportion of total energy investment, is theoretically reasonable and empirically measurable, but it falls short of the scope of green financial instruments, such as green bonds, climate funds, or concessional climate loans, or green credit guarantees. This means that the estimated coefficients, that are unique to renewable energy implementation, might not necessarily be applicable to other avenues of green finance, and it should be taken into consideration when making general extrapolation.

Despite these drawbacks, the research has a range of valuable and unique contributions to the literature of empirical research that prompts appreciable policy implications. Since green investment in lower-income countries has a paradoxical emissions-increasing impact, policymakers and development finance institutions need to resist the one-size-fits-all perspective, but rather they should implement income-differentiated green finance models. In the case of lower-income economies, the focus should be put on the development of the underlying absorptive capacity, through target transfer of technology, technical aid, the design of green industrial policies, and the training of workforce, before engaging themselves in large-scale green investment programmes. Mechanisms of regional coordination based on the African Union and backed by the African Development Bank must be activated to align green investment standards, exchange knowledge and pool financing at the level needed to make a significant change in the industrial energy mix of the region.

The bi-directional causality between regulatory quality and green investment on the governance level highlights that institutional reform should be considered as a co-investment together with climate finance and not as a precondition. Effective regulatory frameworks, proactive regulatory frameworks impose plausible emissions standards. The observation that increasing emissions are resulting in regulatory reactions implies that the governance in the area is still reactive; it will take long term capacity investment in regulatory bodies, anti-corruption policies and political determination to green industrial transformations. Co-ordination of national green finance plans with continental climate plans and international climate finance frameworks such as blended finance mechanisms and concessional funding of multilateral climate funds would further intensify the effects so that green investment in the industrial sector in sub-Saharan Africa would be translated into lasting, equitable, and measurable emissions reductions.

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