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Financial development, sustainable FDI, and carbon intensity of growth in Sub-Saharan Africa

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Abstract

This study uses an unbalanced macro panel framework, drawing on data from 48 Sub-Saharan African (SSA) nations from 2005 to 2023, to evaluate the relationship among financial development, sustainable FDI, and the carbon intensity of growth in the region. Due to strong cross-sectional dependence, which indicates vulnerability to global financial cycles, energy price changes, and climatic concerns, the research uses correlation diagnostics and Driscoll-Kraay standard error regressions to provide consistent inference, with financial development measured through interest rate spread, bank lending rates, and private sector domestic credit. The findings show that financial deepening has varied environmental effects. Domestic credit extension has the most positive impact on carbon intensity, demonstrating that SSA's credit-fuelled growth remains carbon intensive, while lending rates have little explanatory power and interest rate spreads are negatively correlated with carbon intensity, implying contractionary scale effects rather than green technology advances. Sustainable foreign direct investment mitigates credit related emissions when combined with financial growth, but is insufficient on its own, whereas renewable energy consistently reduces carbon intensity, underscoring its role in decoupling growth from emissions. The results suggest that financial development without climate-aligned regulation risks entrenching carbon lock-in across the region, and that financial deepening and FDI policy must align with the Paris Agreement and the Sustainable Development Goals to achieve growth-compatible decarbonisation, contributing to the sustainable finance literature on developing regions.

***Keywords*:** Sustainable FDI, Financial Development, Carbon Intensity, Economic Growth, Sub-Saharan Africa, Panel Data

JEL Classification: Q56, F21, G21, O55

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1. Introduction

Developing economies lead global sustainability discussions as they seek economic growth amid climate change. While Sub-Saharan Africa (SSA) aims to promote growth while avoiding carbon-intensive development trajectories, wealthier economies seek to decarbonize industrial systems. Although SSA contributes minimally to global CO_2 emissions, its emissions have accelerated in the past 20 years due to population growth, urbanization, industrialization, and rising energy needs (World Bank, 2023; Global Carbon Atlas, 2024). To preserve Sub-Saharan Africa's growth trajectory, the carbon intensity of economic growth emissions per unit of GDP is more important than raw emission levels. Financial sector growth and FDI inflows have accelerated regional development. Many Sub-Saharan African countries have increased lending and investment finance through banking reforms, capital market growth, and financial inclusion (Beck, Demirgüç-Kunt, & Levine, 2010). Energy, infrastructure, manufacturing, and services have seen more FDI in Sub-Saharan Africa (UNCTAD, 2023). These changes pose critical considerations regarding whether financing and FDI encourage sustainable growth or carbon-intensive frameworks.

Financial development may hurt growth and the environment. Efficient financial institutions raise long-term capital, lower financing costs, and promote renewable energy, energy-efficient production, and greener technology (Levine, 2005; Yiadom et. al., 2023a; Fosu et al., 2025). Financial deepening may encourage polluting enterprises in SSA economies with low regulation and significant fossil fuel consumption (Adams & Klobodu, 2018; Alpha et al., 2025). Financial development in low-income and lower-middle-income communities may raise or decrease carbon intensity. Current literature and policy discussions have numerous interrelated shortcomings that prompted our analysis. The empirical research on SSA initially focuses on overall CO_2 emissions, which may not be useful for analyzing green growth in low-emitting but rapidly developing economies. Whether economic growth is getting cleaner or dirtier is better measured by carbon intensity. Despite growing recognition of FDI heterogeneity, the literature mostly focuses on overall FDI inflows, ignoring sustainable and conventional FDI. Third, dynamic and endogeneity-robust econometric approaches underrepresent SSA, making causal inference difficult. Despite its importance for policymaking, financial development's moderating effect on sustainable FDI's environmental implications has received little empirical attention.

The policy implications of these gaps are growing. Multilateral development banks are helping Sub-Saharan African countries execute green finance strategies, climate-aligned investment frameworks, and energy transition plans. There is growing concern that weak financial systems and homogenous investment promotion policies could undermine these measures by promoting carbon-intensive development. Understanding how financial development and sustainable foreign direct investment affect carbon intensity is essential for creating coherent policies that balance development and climate goals. This study examines the influence of financial development and sustainable foreign direct investment on the carbon intensity of economic growth in Sub-Saharan

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Africa, utilizing a multi-country panel and dynamic estimation methods. Specifically, the study analyzed the impact of financial development on carbon intensity of growth in SSA, evaluated the influence of FDI inflows on carbon intensity in SSA, and assessed the extent to which financial development amplifies the environmental advantages of sustainable FDI in SSA. The study provides innovative insights into the conditions under which Sub-Saharan African countries might decouple growth from carbon emissions by merging features of financial development with sustainability-focused foreign direct investment measures and emphasizing carbon intensity above emissions levels. This contributes to the empirical literature on sustainable development and offers evidence-based direction for policymakers aiming to leverage finance and investment for a low-carbon future.

2. LITERATURE REVIEW

2.1 Theoretical Literature

2.1.1 Financial Development Theory

The depth, efficiency, and allocation functions of financial systems affect real-sector results, including industrial structure, technical selection, and environmental performance, according to the theory of financial development. According to classical and modern financial development theories, efficient financial institutions mobilize savings, minimize information and transaction costs, and distribute capital to productive ventures, affecting economic activity (Levine, 2005; Yiadom et. al., 2023b; Ofosu-Mensah Ababio et. al., 2024a). This suggests that financial growth in Sub-Saharan Africa might boost carbon-intensive industrialization by boosting credit to fossil fuel-dependent sectors or green industrialization by financing cleaner technology and sustainable foreign direct investment. The idea states that institutional quality and regulatory frameworks determine whether financial depth promotes innovation and energy efficiency or scale impacts and emissions. This conditionality matches the study's examination of financial development indicators and sustainable foreign direct investment, incorporating modern financial development theory that incorporates climate risk, green finance, and sustainability goals in accordance with the Paris Agreement and the Sustainable Development Goals.

2.1.2 Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve (EKC) hypothesis underpins the study by offering a theoretical framework to comprehend the relationship between financial development, sustainable foreign direct investment (FDI), and carbon intensity in Sub-Saharan Africa during several stages of development. The Environmental Kuznets Curve (EKC) asserts that environmental degradation initially escalates with economic and industrial growth due to scale effects, but then diminishes as income levels rise, technology advances, and environmental regulations become more stringent (Grossman & Krueger, 1995; Yiadom et. al., 2023; Ofosu-Mensah Ababio et. al., 2024b). In the face of industrialization among SSA economies predominantly located in the ascending or

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transitional phase of the EKC, financial growth and FDI are expected to exacerbate carbon emissions unless integrated with green technologies, institutional capabilities, and sustainable investment methodologies. Sustainable foreign direct investment and green financing serve as mechanisms through which Sub-Saharan African nations can either flatten or move the Environmental Kuznets Curve lower by enhancing access to cleaner production techniques and energy efficiency. This theoretical framework corresponds with the study's focus on structural transformation amid climate constraints and underscores the importance of investigating whether financial deepening and foreign direct investment foster carbon-intensive growth or facilitate earlier decoupling in accordance with the Paris Agreement and Sustainable Development Goal 13 (Grossman & Krueger, 1995; Shahbaz et al., 2022; Ofosu-Mensah Ababio et. al., 2024c).

2.1.3 Pollution Haven Hypothesis (PHH)

The Pollution Haven Hypothesis (PHH) directly underpins this paper by asserting that multinational corporations often transfer pollution-intensive production to nations with lax environmental regulations, reduced compliance costs, and nascent financial and industrial framework conditions prevalent in numerous industrialization-oriented Sub-Saharan African (SSA) economies. As SSA nations enhance their financial sectors and seek to attract foreign direct investment to facilitate industrialization, they may unintentionally become hubs for carbon-intensive ventures if sustainability requirements are inadequate or ineffectively enforced. This theoretical framework rationalizes the investigation of how sustainable and non-sustainable FDI, in conjunction with financial development, influences the carbon intensity of growth.

The PHH posits that financial deepening devoid of environmental stipulations may promote the influx and domestic growth of polluting companies, hence entrenching carbon lock-in and jeopardizing climate objectives (Copeland & Taylor, 2004; Cole et al., 2017; Prasad et al., 2025a; Acolatse et al., 2026). Conversely, harmonizing FDI policies with green finance principles and international environmental obligations such as the Paris Agreement and SDG 12 (Responsible Consumption and Production) can mitigate pollution-haven dynamics, rendering the hypothesis particularly pertinent for comprehending the finance-FDI-environment nexus examined in this study.

2.2 Empirical Literature

Empirical studies on the interconnections between financial development, foreign direct investment (FDI), and environmental results have proliferated significantly in the last twenty years. Nevertheless, the data is scattered, especially in Sub-Saharan Africa (SSA), and is marked by inconsistent findings, methodological discrepancies, and insufficient focus on carbon efficiency and the quality of foreign direct investment (FDI).

2.2.1 Financial Development and Carbon Intensity

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Recent research explores the impact of financial development on environmental performance, including CO_2 emissions and ecological footprint. Financial growth helps high-income nations cut emissions by stimulating technical innovation and cleaner production, but not low-income countries with poor regulatory frameworks, according to Tamazian, Chousa, and Vadlamannati (2009). Sub-Saharan Africa, with its underdeveloped banking sector and carbon-intensive energy infrastructure, highlights this difference. Shahbaz et al. (2013) use panel data from emerging economies to show that financial development reduces long-term emissions through efficiency-enhancing effects but raises short-term emissions due to scale effects. Acheampong (2019) employs dynamic panel estimators to show that financial development improves environmental quality only after institutional quality reaches a minimum. The findings suggest governance and structure affect financial development sustainability.

Africa research lacks optimism. Adams and Klobodu (2018) discovered that financial development in Sub-Saharan African economies leads to higher CO_2 emissions due to unequal environmental regulation and credit distribution favoring fossil fuels. Financial development increases emissions in energy-intensive African industries, according to Bekun, Alola, and Sarkodie (2019). Most studies use aggregate emissions, disguising whether development is becoming more or less carbon-efficient. A recent study says carbon intensity is a better sustainability metric. Acheampong et al. (2020) demonstrate that financial development reduces carbon intensity in nations with diverse energy compositions, emphasizing energy structure. This study fills a critical empirical gap in Sub-Saharan Africa carbon-intensity calculations.

2.2.2 Foreign Direct Investment, Sustainability, and Environmental Outcomes

Foreign direct investment's environmental impacts have been studied using the Pollution Haven and Halo Hypotheses. Emerging fields lack conclusive data. Pao and Tsai (2011) employ Granger causality tests for BRIC nations and conclude that FDI increases emissions, validating the pollution haven hypothesis. Eskeland and Harrison (2003) indicate that transnational enterprises clean the environment better than local ones due to better technology and management. African evidence is ambiguous and context-dependent. In Africa with permissive environmental policies, FDI increases emissions, according to Abdouli and Hammami (2017).

FDI reduces emissions in host nations with sufficient absorptive capacity and institutional quality, Demena and Afesorgbor (2020). These varied findings suggest that FDI is not uniform. Recent empirical study stresses FDI quality and sustainability. Greenfield foreign direct investment in renewable energy and low-carbon sectors has expanded in growing regions like Sub-Saharan Africa, notwithstanding inequalities, according to UNCTAD (2023). According to Ahmed et al., (2022), sustainability-oriented FDI reduces emissions intensity in emerging economies, but traditional FDI harms the environment. SSA research often utilizes FDI inflows as a percentage of GDP. Most SSA research focuses on emissions levels, not the carbon intensity of growth, limiting

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knowledge of FDI's green structural transformation benefits. This absence is concerning, given SSA's low absolute emissions and quickly rising carbon intensity from expansion.

2.2.3 Joint Effects of Financial Development and FDI on Carbon Intensity

Few studies study how financial development and foreign direct investment influence the environment, despite substantial theoretical support. Financial development can increase financing, technology, and absorptive capacity to boost foreign direct investment's environmental advantages (Beck et al., 2010; Prasad et al., 2025b). Non-African empirical investigations support this complementarity. Financial liberalization increases foreign direct investment's emission-reducing impact in transition economies, say Tamazian and Rao (2010). Charfeddine and Kahia (2019) show that financial development moderates the FDI-emissions relationship in developing market panels, changing pollution haven effects into pollution halo effects. Khan et al., (2021) demonstrate that green finance channels reduce FDI carbon efficiency. Sub-Saharan African evidence is limited. Finance–environment or FDI environment models rarely include interaction effects and dynamic feedback mechanisms. Growth, finance, and emissions are reversely causal, hence interaction terms exhibit endogeneity bias. SSA states have considerable governance quality disparities, but few studies examine institutional heterogeneity.

Many SSA studies use static fixed effects or pooled OLS estimators, which cannot account for carbon intensity persistence or simultaneity bias. Dynamic panel methods like System GMM and Driscoll-Kraay Errors are underutilized despite their appropriateness for large cross-sectional SSA datasets with constrained temporal dimensions. Empirical research has four primary gaps. First, SSA-centric studies employ aggregate emissions instead of the carbon intensity of expansion, which hinders sustainable development research. Second, literature usually considers FDI as uniform, dismissing green FDI's expanding importance. Third, Sub-Saharan Africa's dynamic financial development-sustainable foreign direct investment link is poorly understood. Finally, endogeneity and dynamic adjustment neglect hamper causal inference. Financial development and sustainability-focused FDI indicators in a dynamic panel framework increase empirical literature and inform policy on how SSA economies can separate economic growth from carbon emissions.

2.3 Hypothesis Development

Based on the factual deficiencies and theoretical assertions presented above, the study proposes the following hypotheses:

H_1: Financial development reduces the carbon intensity of economic growth in SSA countries

This hypothesis is based on financial development theory, which asserts that more advanced and efficient financial systems enhance capital allocation to cleaner technologies and energy-efficient industries. Although previous SSA research frequently identifies negative environmental consequences, its dependence on aggregate emissions and static models fails to clarify the effects on carbon intensity.

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H_2: Financial development positively correlates with sustainable foreign direct investment in SSA countries.

Financial development enhances the depth, efficiency, and accessibility of financial systems in Sub-Saharan Africa, thereby reducing financing constraints and investment risks faced by foreign investors. Well-functioning financial markets facilitate capital mobilization, risk sharing, and project financing, which are critical for attracting sustainability-oriented and long-term FDI. Consequently, higher levels of financial development are expected to be positively associated with increased inflows of sustainable foreign direct investment in SSA economies.

H_3: Sustainable FDI inflows reduce the carbon intensity of economic growth in SSA countries

This hypothesis is based on recent empirical evidence that supports the pollution halo effect when foreign direct investment prioritizes sustainability. The hypothesis directly addresses a significant shortcoming of the SSA literature by differentiating green and quality-adjusted FDI from total inflows.

H_4: Financial development moderates the carbon-intensity reducing effect of sustainable FDI in SSA countries.

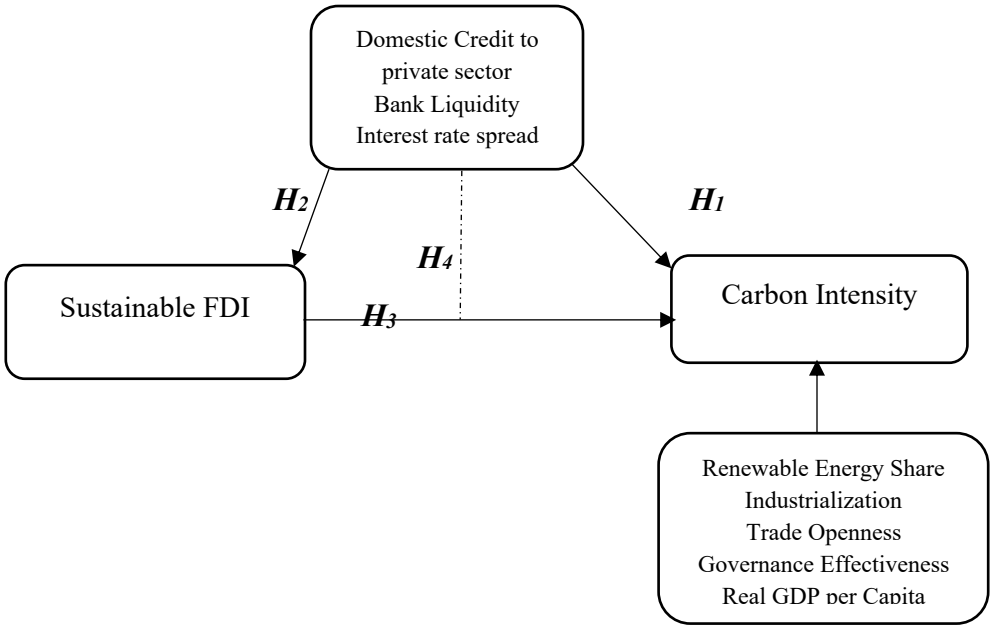
This hypothesis encapsulates the interaction process proposed by both theoretical frameworks and developing empirical evidence. Robust finance systems improve absorptive capacity, facilitate local co-financing, and increase technological spillovers from sustainable foreign direct investment, thus strengthening its environmental advantages.

2.4 Conceptual Framework

The conceptual framework in Figure 1 below, asserts that financial development directly impacts carbon intensity through the efficiency of capital allocation, whereas sustainable foreign direct investment influences it directly through technology transfer and cleaner manufacturing methods. Financial growth also influences the link between FDI and carbon intensity by improving absorptive capacity. Control variables energy composition, industrialization, trade liberalization, and governance impact carbon intensity via structural and regulatory mechanisms.

DOI: https://doi.org/10.56879/ijbm.v5i2.92

Figure 1. Conceptual Framework



Source: Author's own diagram

3. Methodology

The study employed an unbalanced panel from forty-eight (48) Sub-Saharan African nations from 2005 to 2023. The selection of the study timeframe was substantiated by the confluence of structural transformation, financial deepening, and climate policy developments that characterized the period. Post 2010, there has been a rapid increase in FDI-driven industrialization in Sub-Saharan Africa, accompanied by significant growth in domestic credit markets and enhanced integration into global value chains, especially in manufacturing and energy-intensive industries (World Bank, 2020; UNCTAD, 2023).

This period coincides with significant global sustainability milestones, including the Paris Agreement (2015), the Sustainable Development Goals (SDGs), and the emergence of sustainable finance frameworks, which transformed the environmental and financial conditions governing capital flows to developing regions like Sub-Saharan Africa. Economies in Sub-Saharan Africa are particularly significant as they confront the dual challenge of funding industrial expansion while circumventing carbon-intensive development lock-ins, positioning them as a natural laboratory for analyzing the interplay between sustainable foreign direct investment and financial sector development in influencing carbon intensity dynamics. The sample thus encompasses both pre- and post-Paris policy frameworks and represents nations where the growth-environment trade-

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off is most pronounced and pertinent for climate-aligned developmental trajectories (IPCC, 2022; World Bank, 2023).

3.1 Data and Data Sources

All variables are sourced from reputable and extensively utilized international databases, guaranteeing transparency and replicability:

Carbon intensity (CI): Defined as CO_2 emissions (metric tons) per unit of real GDP (constant 2015 USD), derived from the World Development Indicators (WDI) and corroborated with the Global Carbon Atlas (World Bank, 2023; Global Carbon Atlas, 2024).

Financial development (FD) is represented by indices from the World Bank Global Financial Development Database, which measures:

Financial depth (private credit to GDP); Financial access (bank branches, account ownership), and efficiency (interest rate spread) within financial institutions and markets (Beck et al., 2010; Dziwornu et al., 2023). The disaggregation of financial development corresponds with findings that various dimensions have disparate environmental impacts (Svirydzenka, 2016; Mensah, Andoh, et al., 2022; Amankwa et al., 2024).

Sustainable Foreign Direct Investment (SFDI): Assessed with UNCTAD greenfield FDI statistics in ecologically pertinent sectors (renewable energy, low-carbon manufacturing, sustainable infrastructure), supplemented by OECD FDI Quality Indicators when applicable (UNCTAD, 2023; OECD, 2022; Demena & Afesorgbor, 2020).

Control variables: Obtained from the World Development Indicators, International Monetary Fund World Economic Outlook, Worldwide Governance Indicators, and International Energy Agency databases. These variables include: renewable energy share, industrial value added as % to GDP, trade openness, governance effectiveness, and real GDP per capita. These controls are conventional in environmental economics research and assist in alleviating omitted variable bias (Grossman & Krueger, 1995; Acheampong, 2019). The control variables would apply through all models below.

3.2 Model Specification

Driscoll-Kraay standard errors are considered the most suitable estimation method in this context. The cross-section dependence (CD) findings indicate that numerous macroeconomic and external sector indicators (e.g., GDP, import, export, renewable energy utilization) display substantial contemporaneous association among SSA nations, suggesting that shocks and spillovers are collectively experienced (Pesaran, 2015). In these instances, traditional panel estimators with clustered standard errors may underestimate the actual sample variability due to their assumption of cross-sectional independence.

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The study used Driscoll-Kraay standard errors because they are resilient to heteroskedasticity, serial correlation, and cross-sectional dependence, regardless of panel dimensions, rendering them especially appropriate for panels with a moderate number of time periods and potentially interconnected cross-sectional units (Hoechle, 2007; Driscoll & Kraay, 1998). Considering the pronounced cross-sectional patterns in variables like renewable energy consumption and GDP per capita, employing Driscoll-Kraay errors guarantees that the inference on coefficients, particularly regarding financial development and sustainable FDI terms, is not distorted by unaccounted contemporaneous correlation. Incorporating Driscoll-Kraay into the technique enhances the robustness and trustworthiness of the calculated correlations among financial development, SFDI, and carbon intensity outcomes in SSA.

Recent empirical macro-panel analyses examining the interactions between environment-growth and finance-sustainability frequently employ this methodology in the presence of cross-section dependence, as it yields consistent standard errors despite arbitrary correlation patterns in residuals across countries and over time (Hoechle, 2007; Sharma & Paramati, 2021; Vassiliades et al., 2022). By explicitly adjusting for cross-sectional dependence, the study's results more accurately represent the interrelated economic and environmental conditions of Sub-Saharan Africa, hence enhancing confidence in policy-relevant conclusions on the influence of sustainable investment and financial structure on carbon intensity of growth.

The study could use Panel-Corrected Standard Errors (PCSE) or Common Correlated Effect (CCE) estimators, which reduce heteroskedasticity and contemporaneous correlation in panel data and are widely used in macro-panels and work best with extended time dimensions with limited cross-sectional dependence. However, the presence of strong cross-sectional dependence among key variables makes these two estimators not suitable, hence the use of Driscoll-Kraay.

Baseline model 1

Financial Development and Carbon Intensity

The initial baseline model analyzes the direct impact of financial development on the carbon intensity of economic growth, while accounting for conventional structural and institutional variables:

$$CI_{it} = \alpha_0 + \alpha_1 CI_{it-1} + \beta_1 FD_{it} + X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

CI_{it} = carbon intensity of growth (CO_2 emission per unit of real GDP)

CI_{it-1} = lagged carbon intensity, capturing persistence

FDI_{it} = financial development index (depth, access, efficiency)

X_{it} = vector of control variables

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μ_i = country fixed effects

λ_t = time fixed effects

ε_{it} = error terms

Baseline Model 2

Sustainable FDI and Carbon Intensity

The second baseline model examines the independent impact of sustainable foreign direct investment on carbon intensity, addressing objective 2 and hypothesis 2 of this study.

$$CI_{it} = \alpha_0 + \alpha_1 CI_{it-1} + \beta_1 SFDI_{it} + X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: $\mathbf{SFDI_{it}}$ = sustainable foreign direct investment inflows

This illustrates the pollution halo concept, which posits that sustainability-focused foreign direct investment incorporates cleaner technologies and management practices.

Main Model (with interaction)

The primary empirical model incorporates an interaction term between financial development and sustainable foreign direct investment (FDI) to examine whether financial development influences the environmental effects of sustainable FDI.

$$CI_{it} = \alpha_0 + \alpha_1 CI_{it-1} + \beta_1 FD_{it} + \beta_2 SFDI_{it} + \beta_3 (FD_{it} * SFDI_{it}) + X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \ldots\ldots\ldots (3)$$

Where:

CI_{it} = carbon intensity of growth (CO_2 emission per unit of real GDP)

CI_{it-1} = lagged carbon intensity, capturing persistence

FDI_{it} = financial development index (depth, access, efficiency)

$SFDI_{it}$ = sustainable foreign direct investment

(FD_{it} * $SFDI_{it}$) = interaction term of financial development and sustainable foreign direct investment

X_{it} = vector of control variables

μ_i = country fixed effects

λ_t = time fixed effects

ε_{it} = error terms

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4. Results and Discussions

This session presents a summary of findings and a discussion of results based on analyzed data for the study period. Also captured were various statistical tests and discussions on normality and validity instruments used in the model estimation.

Table 1. Cross-Sectional Dependency Test

Variable	CD-test	p-value	average Joint T	mean (ρ)	Mean abs (ρ)
ci	0.531	0.595	19	0.00	0.46
dcps	-0.039	0.969	19	0.00	0.36
irs	0.507	0.612	19	0.00	0.15
fr	85.342	0.000	19	0.58	0.59
nfdi	-0.428	0.669	19	0.00	0.16
nfdi_gdp	4.403	0.000	19	0.03	0.23
rec_eu	98.889	0.000	19	0.68	0.69
iva_gdp	4.093	0.000	19	0.03	0.38
impot	10.273	0.000	19	0.07	0.37
expot	4.605	0.000	19	0.03	0.28
gdp_	8.62	0.000	19	0.06	0.58
gdp_pc	20.279	0.000	19	0.14	0.50
gerr	3.087	0.002	19	0.02	0.28
blr_a	0.724	0.469	19	0.00	0.27

Source: Author's own computation

Pesaran's (2004, 2015) cross-sectional dependence (CD) tests for the variables used to study financial development, sustainable foreign direct investment (SFDI), and carbon intensity of growth in Sub-Saharan Africa are shown in **Table 1**. In Sub-Saharan Africa, where trade, banking, energy markets, and environmental spillovers are interconnecting economies, the CD test measures shock transmission. Variables have varying cross-sectional dependence. Carbon intensity indicators (CI), domestic credit to the private sector (DCPS), interest rate spread (IRS), net FDI inflows (NFDI), and bank liquidity ratio (BLR_A) have statistically insignificant cross-dependence (CD) statistics (p-values > 0.10), indicating minimal contemporaneous spillovers among nations. This suggests that carbon intensity and financial depth indices are country-specific, reflecting energy mixes, industrial architectures, and financial sector maturity across SSA nations. This finding supports previous findings that Sub-Saharan Africa's environmental and financial systems are fragmented, preventing shocks from spreading quickly (Acheampong et al., 2020; Shahbaz, 2022).

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Many macroeconomic and external sector factors are cross-sectionally dependent and statistically significant. Foreign reserve ratios (frr), renewable energy consumption (rec_eu), imports (impot), exports (expot), GDP growth (gdp_g), GDP per capita (gdp_pc), government effectiveness (gerr), FDI-to-GDP ratio (nfdi_gdp), and investment activity each reject the null hypothesis of cross-sectional independence at 1% or 5% significance levels. Significant regional spillovers are shown by high CD statistics for renewable energy consumption (CD = 98.889) and foreign reserves (CD = 85.342), together with elevated mean pairwise correlations (ρ). Shared energy markets, global capital flows, commodity price fluctuations, and synchronized macroeconomic responses to external shocks like climate policies, financial tightening, and geopolitical disruptions are integrating SSA economies (IMF, 2023; World Bank, 2024).

A large cross-sectional dependence in trade, income, energy, and governance variables affects the study's main theme. Initial assumptions are that energy transitions, trade liberalization, and macroeconomic synchronization affect Sub-Saharan Africa's carbon intensity of growth. This supports the idea that SFDI can affect environmental outcomes through supplier chains, knowledge transfer, and regulatory harmonization (Pazienza, 2019; Demena & Afesorgbor, 2020). The considerable link in financial and macroeconomic aggregates highlights the need to account for unobserved shared characteristics when examining the finance-FDI-environment interaction. Neglecting this can lead to biased and inconsistent calculations, especially in SSA panels with small cross-sections and long temporal dimensions (Pesaran, 2015). These findings justify using second-generation panel estimators like Driscoll-Kraay as used in this study. This method matches recent empirical studies on sustainable finance and environmental outcomes in underdeveloped countries (Acheampong et al., 2020; Nathaniel, 2023). The findings show that financial development and SFDI plans to reduce carbon intensity must address regional spillovers, including energy markets, trade integration, and institutional quality. Coordinated green financing and environmental criteria may function better than national approaches.

The CD test results show that while financial development and carbon intensity are country-specific, SSA economies are becoming increasingly integrated, affecting FDI and growth sustainability. This emphasizes the need for a regionally informed empirical approach and supports the idea that sustainable development in Sub-Saharan Africa requires domestic reforms and cross-border policy coordination.

DOI: https://doi.org/10.56879/ijbm.v5i2.92

Table 2. Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) ci	1.00													
(2) dcps	0.19	1.00												
(3) irs	0.00	0.04	1.00											
(4) fr	0.11	0.03	0.09	1.000										
(5) nfdi	0.11	0.16	0.11	0.051	1.00									
(6) nfdi_gdp	0.08	0.04	0.02	0.068	0.15	1.00								
(7) rec_eu	0.36	0.15	0.10	0.538	0.02	0.00	1.00							
(8) iva_gdp	0.18	0.02	0.02	0.045	0.10	0.02	0.05	1.00						
(9) impot	0.15	0.01	0.07	0.133	0.01	0.10	0.13	0.19	1.00					
(10) expot	0.18	0.04	0.12	0.045	0.00	0.08	0.09	0.21	0.48	1.00				
(11) gdp_	0.07	0.04	0.02	0.114	0.07	0.04	0.17	0.02	0.14	0.04	1.00			
(12) gdp_pc	0.02	0.01	0.08	0.234	0.04	0.12	0.25	0.11	0.13	0.14	0.02	1.00		
(13) gerr	0.25	0.16	0.17	0.097	0.10	0.10	0.12	0.04	0.14	0.13	0.04	0.10	1.00	
(14) blr_a	0.13	0.21	0.11	0.043	0.01	0.06	0.15	0.08	0.08	0.09	0.06	0.00	0.06	1.00

Source: Author's own computations

The correlation matrix in Table 2 above, provides initial insights into the relationships between financial development, sustainable foreign direct investment (FDI), and carbon intensity of growth (CI) in Sub-Saharan Africa (SSA), while suggesting that multicollinearity is unlikely to be a major issue since most pairwise correlations are moderate. Carbon intensity (CI) is negatively correlated with renewable energy consumption in final energy use (rec_eu; -0.368), suggesting that adopting renewables leads to lower carbon intensity growth. This supports theoretical frameworks and recent empirical findings that renewable energy reduces emissions intensity in developing countries by dissociating economic growth from fossil fuel consumption (IEA, 2023; Shahbaz et al., 2022). The Carbon Intensity (CI) has modest positive correlations with indicators of industrial activity and trade openness, such as industrial value added (IVA_GDP; 0.185), imports (impot; 0.159), and exports (expot; 0.188), which match the structural characteristics of Sub-Saharan African economies, where manufacturing and trade growth often depends on carbon-intensive energy sources due to weak environmental regulation.

Carbon intensity and environmental variables affect financial development indicators differently. Domestic credit to the private sector (dcps) has a weak positive correlation with ci (0.190), suggesting that financial deepening may still favor carbon-intensive activities over green ones. This supports previous claims that finance can exacerbate environmental restrictions when sustainability considerations are lacking (Zhang et al., 2021). However, the interest rate spread

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(irs) and financial reforms (fr) do not correlate with cii, suggesting that price-based financial indicators may not directly alter emissions outcomes without green finance activities. The financial reform ratio (fr) has a strong positive correlation with renewable energy consumption (rec_eu; 0.538), suggesting that financial reforms may encourage investment in cleaner energy technologies, supporting recent findings on the impact of financial liberalization on renewable energy deployment (Paramati et al., 2022).

Sustainable FDI proxies (nfdi and nfdi_gdp) show moderate correlations with most variables and a slight negative correlation with carbon intensity (-0.111 for nfdi), suggesting that FDI inflows in non-financial or productive sectors may promote cleaner production frameworks. According to the "pollution halo" theory, international enterprises may bring cleaner technologies and better management to host countries. The positive correlations between renewable energy utilization, GDP per capita (0.253), and financial reform indicators suggest that higher income levels and better institutional-financial frameworks lead to cleaner energy transitions in Sub-Saharan Africa, supporting sustainable development literature (World Bank, 2023). Correlation results show economically intuitive patterns that justify multivariate analysis, but estimating the causal effects of financial development and sustainable foreign direct investment on carbon intensity of growth requires econometric methods that account for endogeneity, heterogeneity, and cross-sectional dependence.

Table 3. Regression Result 1 (irs)

VARIABLES	(1) ci	(2) ci	(3) ci
irs	-0.136***	-0.138***	-0.331***
	(0.0368)	(0.0385)	(0.114)
nfdi_gdp		0.0517	-0.00804
		(0.0379)	(0.0613)
IRS * SFDI			0.000456*
			(0.000259)
fr	0.115***	0.110***	0.104***
	(0.0294)	(0.0292)	(0.0282)
rec_eu	-0.666***	-0.662***	-0.663***
	(0.102)	(0.0998)	(0.101)
iva_gdp	0.123*	0.127*	0.132*
	(0.0657)	(0.0651)	(0.0664)
impot	0.0103	0.00619	0.00395
	(0.0282)	(0.0287)	(0.0274)
expot	0.119**	0.117**	0.126**

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	(0.0538)	(0.0530)	(0.0546)
gdp_	0.00330	0.00530	0.0123
	(0.0110)	(0.0137)	(0.0111)
gdp_pc	-0.0148	-0.0199	-0.0215
	(0.0341)	(0.0336)	(0.0335)
gerr	0.325***	0.319***	0.300***
	(0.0489)	(0.0474)	(0.0579)
Constant	397.9***	379.9***	405.3***
	(44.33)	(40.38)	(47.78)
Observations	912	912	912
R-squared	0.227	0.230	0.234
Number of groups	48	48	48

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Source: Author's own computation

Table 3 above presents the regression result of interest rate spread, a measure of financial development, on the dependent variable. The regression results in Columns (1) - (3) show that financial development, sustainable FDI, and structural variables affect Sub-Saharan Africa's carbon intensity of growth (CI). The interest rate spread (irs) is negative and highly significant in all parameters, increasing significantly in Column (3). Narrower spreads indicate that more rigorous or efficient financial intermediation reduces carbon intensity by improving capital allocation and discouraging wasteful, energy-intensive initiatives. This supports the idea that financial efficiency can improve production frameworks when borrowing costs better reflect risk and productivity (Levine, 2005; Shahbaz et al., 2022). The positive and marginally significant interaction term (IRS * SFDI) in Column (3) suggests that financial efficiency's carbon-reducing effect may be reduced when combined with other financial or investment factors, highlighting the conditionality of finance-environment relationships in developing economies.

In Columns (2) and (3), sustainable foreign direct investment as a percentage of GDP (nfdi_gdp) has an inconsistent and statistically inconsequential effect on carbon intensity. This suggests that FDI into SSA does not necessarily promote sustainable growth. FDI may reduce emissions via technology transfer (pollution halo) or increase emissions in host countries with weak environmental regulations (pollution haven), according to mixed evidence in the literature. Financial reforms (fr) are beneficial and significant across all models, suggesting that liberalization or deregulation may initially increase carbon intensity by accelerating industrial activity and energy consumption before environmental safeguards are fully integrated. This supports recent claims that financial reforms without explicit green finance frameworks may worsen environmental restrictions (Zhang et al., 2021).

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Energy infrastructure and industrialization are key. Renewable energy consumption (rec_eu) consistently negatively impacts CI, indicating its crucial role in decoupling economic growth from emissions in SSA. This conclusion strongly supports empirical evidence showing that renewable energy expansion is one of the best ways to reduce carbon intensity in developing countries (IEA, 2023; Acheampong et al., 2020). Industrial value added (iva_gdp) is positive and marginally significant, indicating that manufacturing-driven growth in Sub-Saharan Africa is carbon-intensive due to fossil fuel dependence and little clean technology adoption. Exports (expot) significantly increase carbon intensity, indicating that export-driven growth is mostly reliant on resource- and energy-intensive products, while imports (impot) are negligible, possibly reflecting the diverse composition of imported goods.

Governance and environmental regulation (gerr) have a positive and extremely significant coefficient, suggesting that weak enforcement mechanisms may raise carbon intensity notwithstanding legislative constraints. This shows that many Sub-Saharan African countries lack the regulatory quality to reduce emissions during rapid expansion (World Bank, 2023). Financial efficiency and renewable energy can reduce carbon intensity, while financial reforms, industrialization, and trade development without strong green legislation may increase it. These findings show that Sub-Saharan Africa needs unified policy frameworks that balance financial development, foreign direct investment, renewable energy, and environmental governance to achieve low-carbon growth.

Table 4. Regression Result 2 (blr_a)

VARIABLES	(1) ci	(2) ci	(3) ci
blr_a	0.0504	0.0548	0.0134
	(0.0521)	(0.0528)	(0.0926)
nfdi_gdp		0.0541	0.0167
		(0.0368)	(0.0723)
BLR * SFDI			0.000101
			(0.000127)
fr	0.116***	0.110***	0.110***
	(0.0254)	(0.0246)	(0.0249)
rec_eu	-0.646***	-0.641***	-0.639***
	(0.0980)	(0.0960)	(0.0944)
iva_gdp	0.123*	0.127*	0.128*
	(0.0648)	(0.0642)	(0.0650)
impot	0.0252	0.0210	0.0214
	(0.0338)	(0.0355)	(0.0359)

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expot	0.0995*	0.0968*	0.0985*
	(0.0560)	(0.0553)	(0.0544)
gdp_	0.00262	0.00481	0.00862
	(0.00931)	(0.0111)	(0.0140)
gdp_pc	-0.00903	-0.0143	-0.0136
	(0.0342)	(0.0342)	(0.0342)
gerr	0.301***	0.294***	0.294***
	(0.0485)	(0.0471)	(0.0461)
Constant	362.4***	341.6***	354.2***
	(49.85)	(46.32)	(50.76)
Observations	912	912	912
R-squared	0.224	0.227	0.228
Number of groups	48	48	48

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Source: Author's own computation

Table 4 above present regression result of bank liquidity reserve to asset, a measure of financial development, on other variables of interest. The regression results in Columns (1) - (3) augment the analysis of the influence of financial development, sustainable foreign direct investment (FDI), and structural factors on the carbon intensity of growth (CI) in Sub-Saharan Africa (SSA), with particular emphasis on banking sector conditions indicated by the bank lending rate (blr_a). The coefficient for blr_a is positive but statistically insignificant, suggesting that variations in lending rates do not exert a direct and consistent influence on carbon intensity. This analysis indicates that the cost of credit, when considered independently, is less impactful on environmental outcomes than the distribution of financial resources among sectors.

Recent research suggests that financial depth and efficiency have a greater impact on emissions outcomes than nominal interest rates in developing economies (Levine, 2005; Shahbaz et al., 2022). Similarly, sustainable FDI, shown by nfdi_gdp, remains statistically insignificant in Columns (2) and (3), reinforcing the claim that FDI inflows into SSA do not intrinsically include clean technologies or environmentally sustainable industrial practices. This supports the contradictory empirical evidence concerning the pollution haven and pollution halo hypotheses in Africa, where insufficient environmental regulation and restricted absorptive capacity often hinder the green spillovers from foreign direct investment (Eskeland & Harrison, 2003; Demena & Afesorgbor, 2020).

The interaction term (BLR * SFDI) between bank lending conditions and sustainable FDI is minimal, demonstrating that domestic credit pricing does not considerably affect SSA FDI's

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environmental impact. This suggests that financial systems are unlikely to move foreign capital into cleaner manufacturing without green finance mechanisms like concessional loans for low-carbon developments or sustainability-linked lending. In contrast, financial reforms (fr) have a positive and highly significant effect across all models, demonstrating that financial deepening and liberalization enhance carbon intensity. The scale impact hypothesis states that financial reforms increase industrial activity, energy consumption, and emissions before cleaner technology and laws (Zhang et al., 2021; Zafar, 2023). The importance of connecting financial changes with environmental regulations in Sub-Saharan Africa is highlighted.

Carbon intensity depends on energy structure and manufacturing makeup. Renewable energy consumption (rec_eu) has a large, negative, and statistically significant impact across all models, proving its importance in separating economic growth from emissions. Recent empirical and policy-focused research shows that expanding renewable energy is one of the best ways to reduce carbon intensity in developing countries (Acheampong et al., 2020; IEA, 2023). Industrial value added (iva_gdp) is positive and weakly significant, demonstrating that manufacturing-driven growth in Sub-Saharan Africa remains carbon-intensive due to fossil fuel use and insufficient clean technologies. Trade factors support this narrative: exports (expot) significantly increase carbon intensity, indicating resource- and energy-intensive export frameworks, whereas imports (impot) are insignificant, perhaps due to their diverse composition.

Environmental governance and regulation (gerr) are helpful and significant, suggesting that current regulatory frameworks may be insufficient or poorly enforced, resulting in high carbon intensity during expansion. This study raises concerns that Sub-Saharan African environmental institutions often lag behind economic and financial progress, limiting their ability to steer growth toward a low-carbon path (World Bank, 2023). Renewable energy adoption is a major mitigating element, but financial reforms, industrialization, and export expansion without strong green financing institutions and competent regulation may raise carbon intensity. These findings show that Sub-Saharan Africa needs unified policy frameworks that coordinate financial development, foreign direct investment, renewable energy, and environmental governance to achieve sustainable, low-carbon growth.

Table 5. Regression Result 2 (dcps)

	(1)	(2)	(3)
VARIABLES	ci	ci	ci
dcps	0.104***	0.104***	0.178***
	(0.0283)	(0.0292)	(0.0424)
nfdi_gdp		0.0485	0.105***
		(0.0359)	(0.0249)
DCPS * SFDI			-0.000168*

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			(8.23e-05)
fr	0.0997***	0.0948***	0.0948***
	(0.0279)	(0.0267)	(0.0270)
rec_eu	-0.618***	-0.614***	-0.616***
	(0.101)	(0.0991)	(0.102)
iva_gdp	0.132*	0.135*	0.133*
	(0.0669)	(0.0664)	(0.0661)
impot	0.0297	0.0260	0.0241
	(0.0326)	(0.0337)	(0.0335)
expot	0.0986	0.0964	0.0986
	(0.0575)	(0.0568)	(0.0589)
gdp_	0.00325	0.00509	0.00147
	(0.0115)	(0.0136)	(0.0152)
gdp_pc	-0.0116	-0.0163	-0.0199
	(0.0349)	(0.0347)	(0.0356)
gerr	0.281***	0.275***	0.278***
	(0.0483)	(0.0474)	(0.0451)
Constant	343.5***	326.5***	304.9***
	(47.67)	(44.71)	(45.13)
Observations	912	912	912
R-squared	0.232	0.234	0.236
Number of groups	48	48	48

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Source: Author's own computations

The above table shows the regression results of domestic credit to the private sector on other variables of interest in the study. The regression results in Columns (1) - (3) of Table 5 above show how financial development, sustainable FDI, and structural factors affect Sub-Saharan Africa's carbon intensity of growth (CI). Domestic credit to the private sector (dcps) exhibits a positive and very significant coefficient in all specifications, demonstrating that established credit markets have higher carbon intensity. This shows that Sub-Saharan Africa's financial deepening mostly supports carbon-intensive production and consumption, not green or energy-efficient developments. According to the scale effect hypothesis, more loans increase industrial production, energy consumption, and emissions in economies with underdeveloped green financing mechanisms and environmental evaluations. It also supports the assumption that financial prosperity in emerging economies may worsen environmental difficulties before adopting cleaner technologies (Levine, 2005).

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The effects of sustainable FDI, measured as a percentage of GDP (nfdi_gdp), vary. Foreign capital inflows are often associated with higher carbon intensity in Sub-Saharan Africa, since its direct coefficient is minor in Column (2) but positive and statistically significant in Column (3). The pollution haven concept suggests that multinational firms may move carbon-intensive operations to places with fewer environmental restrictions and lower compliance costs (Eskeland & Harrison, 2003; Demena & Afesorgbor, 2020). Financial development and sustainable FDI (DCPS * SFDI) have a negative and weakly significant interaction term, suggesting that more developed domestic credit markets can reduce FDI's carbon footprint. This shows that modern finance systems may improve technical upgrades, firm-level financing alternatives, or absorptive ability, allowing SSA economies to benefit from FDI cleaner spillovers (Alfaro et al., 2010; Acheampong, 2020).

According to prior models, financial reform (FR) continues to be positive and considerably impactful, demonstrating that liberalization and reform measures increase carbon intensity due to increased economic activity and energy use. Without additional environmental controls, financial changes may increase emissions owing to scale (Zhang et al., 2021). Conversely, renewable energy consumption (rec_eu) often has a negative impact, proving its importance in decoupling growth from emissions in Sub-Saharan Africa. This supports global and regional data showing that renewable energy implementation is essential for reducing carbon intensity in developing economies (IEA, 2023; Acheampong et al., 2020). The positive and marginally significant coefficient on industrial value added (iva_gdp) shows that SSA's manufacturing and industrial growth is energy- and carbon-intensive, limiting clean technology adoption.

Ultimately, environmental governance and regulation (gerr) is advantageous and critically important, indicating that existing regulatory frameworks are either insufficient or poorly enforced, which correlates with heightened carbon intensity during expansionary phases. This underscores the institutional inadequacy in Sub-Saharan Africa, where economic and financial advancement often outpaces environmental control (World Bank, 2023). The results demonstrate that while financial development and foreign direct investment can stimulate growth, they frequently increase carbon intensity unless supported by stringent renewable energy legislation, effective environmental regulations, and targeted green finance efforts. These findings highlight the imperative for integrated policy frameworks that align financial deepening and foreign direct investment strategies with low-carbon development objectives in Sub-Saharan Africa.

4.1 Comparing the impact of the measure of Financial Development on Carbon Intensity

The three regression models show that financial sector development measures affect Sub-Saharan Africa's carbon intensity of growth differently and economically. All models show a negative and statistically significant association between carbon intensity and interest rate spread (IRS). Broader spreads indicating higher intermediation costs, credit risk, and financial constraints usually hinder carbon-intensive sectors and energy usage. Stricter financial conditions may reduce emissions in Sub-Saharan Africa by contracting heavy industries and fossil-fuel-dependent sectors, rather than

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by technological improvement. According to the finance-environment literature, restricted lending can reduce emissions in the short term, especially in emerging economies with weak green finance systems (Acheampong et al., 2020; Shahbaz, 2022). However, these emission reductions may be temporary and reduce welfare, contradicting the Paris Agreement's goal of sustainable, growth-compatible decarbonization.

In contrast, bank lending rates (BLR_A) had no significant effect on carbon intensity across parameters. This suggests that nominal lending rates in Sub-Saharan Africa do not affect businesses' productivity or energy choices. The World Bank (2022) and IMF (2023) underline the suppressed effect of SSA financial institutions, which have limited access to long-term credit, high informality, and inadequate policy rate transmission to real-sector investment choices. Thus, loan rate changes do not reliably shift capital to green or carbon-intensive companies. The lack of environmental impact from price-based financial indicators indicates the need for green finance instruments, in line with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action).

Conversely, domestic credit to the private sector (DCPS) has the strongest and most consistent positive influence on carbon intensity, making it the most important financial development statistic. Credit availability increases emissions intensity, demonstrating scale effects in which funding encourages industry growth, fossil fuel use, and resource-intensive development without environmental restrictions. In developing countries, financial deepening without green laws worsens environmental degradation (Sadorsky, 2010; Acheampong et al., 2019). The interaction results show that sustainable FDI can reduce credit-driven carbon intensification, but not altogether. Global obligations like the Paris Agreement, Glasgow Climate Pact, and G20 Sustainable Finance Roadmap emphasize the need for financial depth to meet climate goals. Neglecting climate risk, green credit rules, and sustainability-linked financing in Sub-Saharan Africa's financial development hinders Sustainable Development Goals 7, 12, and 13, perpetuating carbon lock-in instead of green structural transformation.

5. Conclusions and Recommendations

This study offers substantial empirical evidence that financial development and sustainable foreign direct investment (FDI) have large and interrelated impacts on the carbon intensity of growth in Sub-Saharan African (SSA) economies. The existence of significant cross-sectional dependence indicates that SSA nations are collectively influenced by global financial cycles, climate-related disturbances, and fluctuations in energy prices, hence emphasizing the regional and systemic characteristics of sustainability issues. Regression results demonstrate that whereas financial depth and credit expansion promote economic activity, they correlate with increased carbon intensity in the absence of robust environmental protections, highlighting scale impacts and carbon-biased industrial frameworks. Sustainable foreign direct investment (FDI) demonstrates contingent environmental results, indicating that in the absence of sufficient green financing structures and

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institutional capabilities, FDI-driven growth may exacerbate emission-intensive development trajectories.

Renewable energy use continually decreases carbon intensity, underscoring its crucial function in divorcing economic growth from emissions and facilitating green structural transformation. These findings closely correspond with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), while also highlighting conflicts with SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure) when growth strategies lack environmental alignment. The research indicates that SSA's developmental path should transition from growth-focused finance to sustainability-oriented financial and investment systems aligned with global climate and sustainable finance obligations. SSA policymakers should incorporate climate risk and sustainability requirements into financial sector rules, along with the Paris Agreement, Glasgow Climate Pact, and UN Principles for Responsible Investment. According to the Network for Greening the Financial System (NGFS) and the G20 Sustainable Finance Roadmap, central banks and financial regulators should implement green macroprudential instruments, undertake climate stress testing, and build sustainable finance taxonomies. Renewable energy finance, green bonds, and sustainability-linked credit incentives would advance SDG 7, 9, and 12 (Responsible Consumption and Production). Harmonizing foreign direct investment regulations with environmental standards and implementing environmental impact assessments will reduce pollution-heavy capital inflows, supporting Agenda 2063 of the African Union and Sustainable Development Goal 13.

To determine how the finance-FDI-environment nexus turns carbon-intensive financial development into climate-friendly consequences, future research should examine threshold and non-linear impacts. In line with the UNFCCC Global Stock take aim, researchers should examine sector-specific green finance, institutional quality, and climate governance as mediating factors. Climate vulnerability indices, green innovation measurements, and transition finance indicators in empirical research will improve policy formulation and evidence-based global sustainability framework implementation.

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