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Financial Development, Carbon Financing and Carbon Emissions in Sub-Saharan Africa

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ABSTRACT

Financial systems hold a dual position in that they foster economic advancement while simultaneously affecting environmental conditions, a dynamic that underscores the need to scrutinize financial development and carbon finance within the Sub-Saharan African context. This paper sets out to analyze the relationship between these two financial factors and carbon emissions in SSA, pursuing two distinct research objectives: assessing the emissions impact of financial development and determining the emissions effect of carbon financing. The investigation utilizes a panel dataset of seven SSA nations with developing capital markets, covering the years 2000 through 2023 and comprising Côte d'Ivoire, Ghana, Kenya, Mauritius, Namibia, Nigeria, and South Africa. Data originated from the World Bank Development Indicators and the IMF Financial Structure Database. Methodologically, the study applies the pooled mean group estimator based on the ARDL model, with the PCSE technique incorporated to maintain robustness despite potential cross-sectional interdependencies. Results reveal a nuanced scenario: financial depth, measured through liquidity indicators, appears to lower emissions substantially, yet both the expansion of private sector credit and the monetary value of share trading exhibit a pronounced positive association with rising carbon output. Regarding carbon financing, climate investment funds significantly affect emissions, while certified emission reduction units show no significant impact. Manufacturing value added remains the primary source of emissions in the region. The findings suggest that financial deepening can support climate sustainability if financial resources are redirected toward environmentally sustainable sectors through targeted regulations and incentives.

Keywords: Carbon Emissions, Carbon Financing, Financial Development, Pooled Mean Group (PMG/ARDL), Sub-Saharan Africa

1. INTRODUCTION

Global warming, environmental degradation and carbon emissions are among the most pressing issues facing humanity, and have been the subject of ongoing concern from governments, policy makers and the academic community in the last 30 years (Habiba & Xinbang, 2022). This problem is largely due to the increase in emissions of greenhouse gases, of which carbon dioxide (CO2) is the most harmful to the health and environment of humans. CO2 emissions from the combustion of conventional energy sources (coal, gas and crude oil) make up about three-quarters of total GHG emissions (Stocker, 2014), and polluting energy sources contribute to about two-thirds of world CO2 emissions (International Energy Agency, 2019). The carbon footprint is an extension of the earlier idea of the ecological footprint put forward by Rees (1992) which measures the demands that human activity places on the planet that exceed its regenerative capacity (Goodland & Anhang, 2009).

SSA occupies a unique position in the climate change discourse. Although the region contributes only a small share of global greenhouse gas (GHG) emissions, it is among the most vulnerable to the adverse impacts of climate change due to its high exposure and limited adaptive capacity (Intergovernmental Panel on Climate Change [IPCC], 2018). Meanwhile, SSA needs to achieve rapid economic growth and the financial system plays a key role in the financing of economic growth. Financial development, in the broad sense of the term, that is, an increase in the size, efficiency, stability and availability of the financial system, can either accelerate or retard emissions, depending on the sectors into which finance is directed. A more efficient and deeper financial system can help to unlock resources for clean technology and green investment, while easier access to credit can help to increase carbon-intensive production and consumption (Sadorsky, 2010; Tamazian et al., 2009).

Carbon financing has also become a market-based tool to reduce emissions, complementing the financial-development channel. Carbon pricing mechanisms like certified emission reduction (CER) units under the Clean Development Mechanism and climate investment funds (CIF) provide incentives to cut energy consumption and transition to cleaner energy sources (Gillenwater & Seres, 2011; Parry, 2021). The relationship between domestic financial development and these international carbon financing flows is therefore a key element in the region's transition towards a low-carbon economy.

Analytically, financial development and carbon financing are rarely modelled together, yet the two channels are not independent: domestic financial depth determines the capacity of an economy to absorb, co-finance and scale up externally sourced carbon-financing instruments such as CIF and CER units, while the presence or absence of dedicated carbon finance can itself alter how domestic credit and equity markets price carbon-intensive versus clean assets. Treating financial development and carbon financing as separate, single-channel analyses, as most prior studies do, risks two forms of omitted-variable bias: estimates of financial development's effect on emissions that do not control for carbon-financing inflows may mistakenly attribute to "finance" an effect that is actually driven by targeted climate funds concentrated in a subset of financially deeper economies, and conversely, estimates of carbon financing's effect that ignore the domestic financial-system context may overstate or understate impact depending on whether a country's credit and capital markets are structurally oriented toward carbon-intensive or clean sectors. Estimating both channels jointly in a single dynamic-panel framework therefore allows their effects to be identified net of one another, rather than conflated, and permits an assessment of which channel dominates once both are held constant, a distinction that matters directly for policy sequencing, since it clarifies whether SSA governments should prioritise domestic financial-sector reform, external carbon-finance mobilisation, or both simultaneously.

Although there is a significant body of literature that has been developed that connects financial development and emissions, the evidence is mixed and most of it comes from China, Europe and the United States. Sub-Saharan Africa's financial landscape, characterized by heavy reliance on banking systems and limited capital market depth, has received scant attention in terms of the combined emission effects of financial development and carbon finance. This study intends to bridge that knowledge gap. To that end, two central questions guide the analysis: examining how financial progress shapes carbon emissions in SSA, and measuring the contribution of carbon financing to emission levels in the region. The study provides evidence directly relevant to the design of green-finance policy in the region by estimating both relationships in a single dynamic-panel framework and by conducting robustness checks.

2. LITERATURE REVIEW

2.1. Conceptual Review

Carbon emissions, which are often referred to as the carbon footprint, encompass the output of carbon dioxide and other greenhouse gases like methane and nitrous oxide. These substances are measured collectively in terms of carbon-dioxide equivalent and are produced when fossil fuels are burned in transport, industry, buildings, and power generation activities (Afriani et al., 2026; Stocker, 2014). Carbon financing is a branch of environmental finance that assigns a price to emissions in order to deter the use of fossil fuels and redirect investment toward cleaner technologies. Its principal instruments include green credit, international emissions trading, the Clean Development Mechanism, certified emission reduction units and climate investment funds (Gillenwater & Seres, 2011). Financial development, in turn, denotes improvements in the size, efficiency and stability of, and access to, a financial system which the capacity of that system to deliver high-quality financial services at low cost without price and non-price impediments (Eryigit & Dulgeroglu, 2015).

2.2. Theoretical Framework

The study is based on Cobb-Douglas production function (Cobb, 1928) that shows output as a function of capital and labour. In an environmental-economic context, the model is expanded to include the fact that the use of capital and labour involves energy use, which produces emissions. The relationship is mediated by financial development, which affects the cost and availability of capital used in production: if finance is directed towards energy-intensive capital, emissions will increase; if finance is directed towards cleaner capital and energy-efficient technologies, emissions will decrease. The framework thus allows for the different emission impacts that financial development and carbon financing can have.

2.3. Empirical Review

The empirical results on the finance-emissions nexus are inconsistent. One side of the story is that financial development leads to higher emissions. For the BRIC economies, Tamazian et al. (2009) concluded that an increase in economic and financial development was linked to environmental degradation, and Rahman and Alam (2022)reported that, for seventeen Asia–Pacific countries between 1960 and 2020, financial development significantly affected CO2 emissions and was supportive of the environmental Kuznets curve hypothesis. Similarly, Yang et al. (2023) found that financial development and upgrading of industrial structure significantly boosted emissions in 283 Chinese cities, and Sadorsky (2010) showed that financial development led to higher energy consumption in emerging economies.

A second strand is opposite. Emenekwe et al. (2021) found that financial development has a negative effect on CO2 emissions and is conducive to the environmental Kuznets curve in a dynamic panel of 37 SSA countries between 2000 and 2016, while Aluko and Obalade (2020) and Xuezhou et al. (2021) reported a positive effect of financial development on environmental quality in SSA mediated by technology. Overall, financial development has been shown to have a negative effect on emissions in African samples (Odhiambo, 2020; Tsaurai, 2019), reflecting the diversity of the region.

There is greater evidence of carbon financing. Guo et al. (2022) identified that the use of green finance had a significant impact on carbon emissions in the Yangtze River Economic Belt in China, with spillover effects to neighbouring provinces being limited. Su et al. (2022) and Umar and Safi (2023) found that green credit and green-finance instruments reduced pollutant emissions, while Al Mamun, Boubaker and Nguyen (2022) found evidence globally that green finance promotes decarbonisation. The same results were obtained by Shen et al. (2021), who showed that green investment and financial development were negative factors in emissions in China. The evidence on certified emission reductions, however, is less clear-cut with some studies casting doubt on whether offset volumes result in measurable reductions. This study is one of the few studies that combines financial development and carbon financing instruments in a single SSA panel.

3. RESEARCH METHODS

The study is an ex-post facto longitudinal study. The population includes the 49 countries that the UNDP (2024)) has identified as being in Sub-Saharan Africa. A stratified sampling method was used to select a sample of seven countries: Côte d'Ivoire, Ghana, Kenya, Mauritius, Namibia, Nigeria and South Africa, which are the largest emitters of carbon dioxide and have relatively developed capital markets in the region. This selection was necessary because several indicators used in the study, particularly stock-market turnover, the value of shares traded, and carbon-financing data, require a level of market depth and data availability that most SSA countries lack; the sample is therefore best understood as representing SSA's more financially developed economies rather than the region as a whole. The data are annual observations from 2000 to 2023 from the World Bank Development Indicators and the International Monetary Fund Financial Structure Database.

Financial development and carbon financing are modelled as a function of carbon emissions (GHG). Financial development is measured using financial liquidity (FINL), bank credit to the private sector as a percentage of GDP (BC_GDP), stock-market turnover (TURN) and the value of shares traded (VASTR). Carbon financing is represented by certified emission reduction units (CERS) and climate investment funds (CIF). Manufacturing value added (MVA) and the urbanisation rate (URB) are included as control variables. The estimated model is specified as:

$$GHGit = \beta_0 + \beta_1 FINL + \beta_2 BC\_GDP + \beta_3 TURN + \beta_4 VASTR + \beta_5 CERS + \beta_6 CIF + \beta_7 MVA + \beta_8 URB + \varepsilon it$$

In this specification, the subscript i identifies each country within the panel, ranging from 1 to 7, while t captures the annual time dimension, spanning 24 years. The disturbance term is represented by ε. For the empirical estimation, the pooled mean group estimator, which falls under the ARDL family of panel techniques, was adopted following Pesaran, Shin, and Smith (2001). This estimator proves suitable for several reasons: it enforces homogeneity on long-run parameters across nations but allows heterogeneity in short-run adjustments, convergence speeds, and error distributions, and it also handles variables with mixed orders of integration. The selection of lag length relied on both the Akaike and Schwarz information criteria, with each criterion converging on a single-period lag.

The panel was first tested for cross-sectional dependence using the Pesaran (2004) CD test, for stationarity using the first-generation Levin–Lin–Chu (Levin et al., 2002) and Im–Pesaran–Shin (Im et al., 2003) tests, and for cointegration using the Pedroni (2004), Kao (1999) and Westerlund (2007) procedures. The panel-corrected standard errors (PCSE) estimator was used as a robustness check since the data are cross-sectionally dependent, which can make the PMG standard errors inefficient (Christopeit & Wooldridge, 2003).

4. RESULTS AND DISCUSSION

4.1. Research Results

4.1.1. Descriptive Statistics

Table 1 summarises the descriptive statistics. The average greenhouse-gas emissions per capita are 3.56 metric tons, although the range of emissions is quite large, from 0.77 to 11.86 metric tons. The level of bank credit to GDP is 47.77 percent, financial liquidity 47.61 percent, and the turnover of the stock market and the value of shares traded are low in comparison with developed markets, reflecting the shallowness of SSA capital markets (Beck & Levine, 2004). All variables have Jarque–Bera statistics that are significant, suggesting departures from normality and justifying the use of a panel estimator that is robust to such features.

Table 1. Descriptive Statistics

Variable	Mean	Max.	Min.	Std. Dev.	Skew.	Kurt.	J-B
GHG	3.56	11.86	0.77	3.10	1.37	3.76	56.59
BC_GDP	47.77	142.42	8.08	39.09	0.75	2.24	19.69
FINL	47.61	159.95	11.30	29.66	1.35	4.75	72.86
TURN	9.44	80.38	0.35	10.97	2.64	13.13	913.19
VASTR	9.67	124.37	0.05	22.98	2.75	10.06	561.12
CERS	1,934,558	19,613,899	7,547	4,038,967	2.78	10.57	617.56
CIF	134,478	700,000	13,500	155,867	1.73	5.35	122.47
MVA	11.58	19.77	5.66	2.82	0.77	3.71	20.14
URB	45.19	68.83	19.89	11.68	-0.26	2.71	6.51

Note. All Jarque–Bera probabilities are significant at the 1% level ($p \leq 0.02$).

Source: Authors' computation (2026)

4.1.2. Correlation Analysis

The correlation matrix (not shown for brevity) indicates that the highest correlation is between emissions and manufacturing value added (0.962), which confirms the importance of industrial activity in emissions. Emission levels are also positively correlated with certified emission reductions (0.876) and climate investment funds (0.783), as the carbon financing mechanisms are targeted at higher emitting economies. Bank credit and financial liquidity are strongly correlated (0.709) within the financial sector, which is bank based. Multicollinearity is not likely to affect the estimates, with the exception of the manufacturing–emissions pair, which has a correlation of 0.84.The only correlation above the conventional 0.80 threshold is between manufacturing and emissions, with a correlation of 0.84, so multicollinearity is not likely to bias the estimates.

4.1.3. Cross-sectional Dependence and Unit Root Tests

The Pesaran (2004) CD test (Table 2) confirms that the null of cross-sectional independence is rejected for all the variables, suggesting that shocks in one country in the SSA are passed on to others via common monetary regimes, regional trade and common climate exposure. This finding supports the use of second generation panel techniques and the PCSE robustness check.

Table 2. Cross-sectional Dependence (CD) Test

Variable	CD-statistic	p-value	|corr|
GHG	152.80	0.00	0.51
BC_GDP	14.31	0.00	0.31
FINL	275.70	0.00	0.65
TURN	184.00	0.00	0.58
VASTR	243.70	0.00	0.75
CERS	12.00	0.02	0.15
CIF	39.96	0.00	0.21
MVA	134.40	0.00	0.45
URB	19.40	0.00	0.28

Source: Authors' computation (2026)

The CIPS panel unit-root test (Table 3) shows a mixed order of integration: some variables are stationary at level, I(0), while others attain stationarity only after first differencing, I(1). This mixture is precisely the setting in which the PMG/ARDL estimator is appropriate.

Table 3. Second-generation Panel Unit Root Test (CIPS)

Variable	Level (stat.)	First diff. (stat.)	Order of integration
GHG	-1.376	-2.860	I(1)
BC_GDP	-0.864	-3.937	I(1)
FINL	-2.762	-4.113	I(0)
TURN	-2.195	-3.661	I(0)
VASTR	-1.083	-2.455	I(1)
CERS	-3.596	-4.659	I(0)
CIF	1.620	-2.498	I(1)
MVA	-1.281	-4.665	I(1)
URB	-2.340	-5.023	I(0)

Note. 5% critical value = −2.34.

Source: Authors' computation (2026)

4.1.4. Cointegration Test

The presence of a long-run relationship among the variables is confirmed by the Westerlund (2007) cointegration test, reported in Table 4, a second-generation procedure that accommodates cross-sectional dependence. Rejection of the no-cointegration null hypothesis occurs for every model specification according to the panel statistics Pt and Pa, with the group-mean statistics providing additional confirmation for the capital-market and climate-fund models. This establishes a persistent long-term equilibrium, a feature that the PMG estimator is well suited to retrieve.

Table 4. Westerlund Cointegration Test

Statistic	Financial development		Capital market		Climate funds	
	Value	p-value	Value	p-value	Value	p-value
Gt	-1.121	0.25	-2.732	0.00	-2.833	0.00
Ga	-4.276	0.00	-1.146	0.34	-3.944	0.00
Pt	-4.326	0.00	-4.326	0.00	-7.002	0.00
Pa	-2.947	0.00	-3.089	0.00	-5.384	0.00

Note. The null hypothesis is no cointegration.

Source: Authors' computation (2026)

4.1.5. Regression Results

Table 5 reports the PMG estimates for the full model. Bank credit to GDP is positive and significant (0.011, p = 0.004) in the long run, indicating that credit penetration increases emissions, while financial liquidity is insignificant. The carbon-financing variables are all significant and negative except for manufacturing value added, which is strongly positive. The error-correction term is negative and significant (−0.204, p = 0.050), which is consistent with a stable long-run relationship with approximately 20 percent of disequilibrium being corrected annually. The value of shares traded is important in the short run, reflecting mostly short-term financial-market impacts.

Table 5. Pooled Mean Group (PMG) Estimation

Variable	Coefficient	t-statistic	Prob.
Long-run equation			
BC_GDP	0.011	2.940	0.004
FINL	0.005	1.262	0.210
TURN	0.006	1.648	0.103
VASTR	-0.002	-0.537	0.592
CERS	-0.090	-5.229	0.000
CIF	-0.403	-4.085	0.000
MVA	1.189	6.502	0.000
URB	0.011	0.951	0.344
Short-run equation			
ECM(t−1)	-0.204	-1.740	0.050
ΔBC_GDP	-0.004	-1.120	0.266
ΔFINL	0.002	0.730	0.467
ΔTURN	0.002	0.996	0.322
ΔVASTR	-0.013	-2.061	0.042
ΔCERS	-0.021	-0.681	0.498
ΔCIF	-0.044	-0.550	0.584
ΔMVA	-0.097	-0.356	0.722
ΔURB	0.246	1.407	0.163
Constant	-2.307	-1.907	0.060

Note. Dependent variable: greenhouse-gas emissions (GHG)

Source: Authors' computation (2026)

Because the panel exhibits cross-sectional dependence, the Panel-Corrected Standard Errors (PCSE) estimator was employed as a robustness check (Tables 5 and 6). The PCSE estimates confirm the robustness of the PMG results by producing consistent coefficient signs and significance levels while providing more efficient estimates. Specifically, bank credit to GDP remains positive and significant (0.004, $p < 0.01$), whereas financial liquidity becomes negative and significant (−0.007, $p < 0.01$), reinforcing the evidence that different dimensions of financial development exert distinct effects on carbon emissions. Similarly, the value of shares traded remains positive and significant (0.004, $p < 0.01$). Among the carbon financing variables, climate investment funds continue to exhibit a significant negative effect on carbon emissions (−0.423, $p < 0.01$), while certified emission reductions remain statistically insignificant. Manufacturing value added remains the strongest positive determinant of carbon emissions (1.030, $p < 0.01$). Furthermore, the adjusted R^2 of 0.986 indicates that the model explains a substantial proportion of the variation in carbon emissions, supporting the robustness and explanatory power of the estimated model.

Table 6. Panel-corrected Standard Errors (PCSE) Estimation - Robustness Check (Long Run)

Variable	Coefficient	t-statistic	Prob.
Constant	-8.207	-29.093	0.000
BC_GDP	0.004	3.662	0.000
FINL	-0.007	-6.175	0.000
TURN	-0.002	-1.388	0.167
VASTR	0.004	2.964	0.004
CERS	-0.019	-1.356	0.177
CIF	-0.423	-14.160	0.000
MVA	1.030	40.110	0.000
URB	-0.028	-24.670	0.000
Adj. R^2	0.986		
F-statistic	1482.8		

Note. Dependent variable: greenhouse-gas emissions (GHG).

Source: Authors' computation (2026)

4.2. Discussion of Findings

Objective one, the effect of financial development on carbon emissions yields a divergent result. Financial liquidity, a measure of financial depth, significantly reduces emissions in the robust PCSE estimates, implying that a deeper financial system channels resources toward more efficient and cleaner uses. This aligns with Emenekwe et al. (2022), Aluko and Obalade (2020) and Shen et al. (2021). In contrast, bank credit to the private sector significantly increases emissions across both estimators, and the value of shares traded does likewise, indicating that the prevailing pattern of credit allocation and capital-market activity still favours carbon-intensive sectors. This is consistent with Tamazian et al. (2009), Sadorsky (2010) and Yang et al. (2022). The implication is that financial development is not intrinsically clean or dirty in SSA; its environmental effect depends on the composition of the finance that is supplied.

Objective two, the effect of carbon financing on carbon emissions also produces a mixed but interpretable result. Climate investment funds exert a strong, robust and statistically significant emission-reducing effect, confirming the value of dedicated climate finance in advancing cleaner energy and sustainable projects, in line with Guo et al. (2022), Su et al. (2022) and Al Mamun et al. (2022). Certified emission reduction units, by contrast, have no significant effect, suggesting that the offset volumes recorded in the region have not translated into measurable abatement, possibly because of thin participation, weak verification and inadequate pricing. Across all specifications, manufacturing value added remains the dominant driver of emissions, reaffirming that industrial activity, rather than finance per se, is the primary source of carbon emissions in SSA.

5. CONCLUSIONS

This study examined the effects of financial development and carbon financing on carbon emissions in seven Sub-Saharan African countries during 2000–2023 using the PMG/ARDL estimator with PCSE robustness checks. The findings reveal that financial development has heterogeneous effects on carbon emissions. Financial liquidity reduces emissions, whereas private-sector credit and stock market activity increase them. Regarding carbon financing, climate investment funds significantly reduce emissions, while certified emission reduction units have no significant effect. Manufacturing value added remains the strongest driver of emissions. Overall, the findings suggest that promoting financial development alone is insufficient to achieve environmental sustainability unless financial resources are directed toward low-carbon economic activities.

Based on these findings, policymakers should deepen financial liquidity while ensuring that credit and capital market expansion are accompanied by green financing policies, such as sustainable lending incentives, differentiated credit schemes, and stronger ESG disclosure requirements. Governments should also expand climate investment funds, given their consistent emission-reducing effect, while improving the effectiveness of certified emission reduction mechanisms through stronger verification and pricing systems. Collectively, these measures would help redirect financial flows toward sustainable sectors and support the transition to a low-carbon economy in Sub-Saharan Africa.

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