“Effect of green finance on green growth in Sub-Saharan Africa: Does FinTech matter?”

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EFFECT OF GREEN FINANCE ON GREEN GROWTH IN SUB-SAHARAN AFRICA: DOES FINTECH MATTER?

Abstract

Amid escalating climate challenges, examining how financial innovation affects sustainable growth in Sub-Saharan Africa (SSA) while informing stronger environmental and financial policy design is a critical priority in environmental management. This study investigates the impact of green finance on green growth in SSA, emphasizing the moderating role of FinTech. Using panel data for 35 countries from 2000 to 2021, it applies the System-GMM estimator to address endogeneity. The results show that green finance significantly promotes green growth at the 1% level. FinTech also plays a critical role, both directly and by enhancing the effectiveness of green finance. Specifically, 1% increase in green finance and FinTech is associated with 5.63 % and 7.62 % gains in green growth, respectively, while their interaction yields an additional 0.22 % increase. The findings highlight the importance of policies that expand green finance through robust regulatory frameworks, innovative financial instruments, carbon pricing mechanisms, and the development of voluntary carbon markets. Leveraging FinTech can further support green investment by improving financial inclusion, lowering transaction costs, and increasing transparency. Strengthening human capital, particularly through environmental education, is essential to support sustainable practices. Besides, greater financial openness can attract foreign investment into green sectors. These measures can help policymakers foster sustainable growth, enhance climate resilience, and advance long-term environmental objectives in the region.

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INTRODUCTION

Since the Industrial Revolution, the dominant economic growth model has generated significant environmental externalities, raising questions about its long-term sustainability (Nordhaus & Tobin, 1971; Nordhaus, 2019). In response to the natural resources' depletion concerns, Hotelling (1931) warned of the intertemporal challenges associated with the exploitation of non-renewable resources. These debates have intensified with the growing impacts of climate change and the increasing recognition that conventional growth strategies often neglect environmental constraints. In response, the concept of green growth emerged as an alternative framework to reconcile economic development with environmental sustainability. Ecological modernization theory argues that technological progress, institutional reforms, public investment in ecological projects, and sustainable production systems can jointly support economic and environmental efficiency (Spaargaren & Mol, 1992; Ali, 2021; Ali & Bayale, 2024). Within this perspective, green finance has become a central mechanism for mobilizing capital toward environmentally sustainable investments and low-carbon infrastructure (Zhao et al., 2023).

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Recent studies suggest that green finance can promote sustainable development by supporting green investments, green credit, and green bonds, thereby reducing carbon emissions and facilitating ecological transition (Irfan et al., 2022; Xiufan & Decheng, 2024). At the same time, financial technology innovations (FinTech) are transforming financial systems by improving transaction efficiency, expanding financial inclusion, and facilitating access to sustainable financing (Murinde et al., 2022; Takeda & Ito, 2021). FinTech may therefore strengthen green finance by reducing information asymmetries and accelerating investments in environmentally friendly projects (Xu et al., 2023a; Wei et al., 2024). However, important concerns remain regarding the effectiveness of green finance instruments, institutional weaknesses, and the environmental effects associated with increased consumption enabled by digital finance (Adekoya et al., 2021; Qin et al., 2022).

These issues are particularly relevant for Sub-Saharan Africa (SSA), where economies face major structural, financial, and institutional constraints. Although sustainable growth has become a global policy objective following COP21, the capacity of SSA countries to simultaneously achieve economic growth and environmental sustainability remains uncertain. The problem addressed in this study, therefore, concerns the extent to which green finance can effectively promote green growth in SSA under existing structural constraints, and whether FinTech development can enhance green finance in supporting sustainable economic transformation.

1. LITERATURE REVIEW

The relationship between green finance and green growth remains widely debated in the economic literature, reflecting both optimistic and skeptical perspectives regarding its effectiveness as a catalyst for sustainable development. Since 2015, the scientific community has shown a growing interest in green finance (Sang, 2024; Irfan et al., 2022; Zhang et al., 2019). On the one hand, several studies argue that green finance plays a crucial role in stimulating green growth and improving environmental outcomes. For instance, Tufail et al. (2024) show that green finance significantly accelerates green growth across 19 OECD countries. Using the quantile regression of moments technique to capture long-term effects, their findings indicate that increased green financial flows support environmentally sustainable economic expansion. Similar conclusions are reached by Udeagha and Ngepah (2023), who apply the CS-ARDL method and demonstrate that green finance contributes to environmental sustainability in BRICS countries. Green finance is composed of various dimensions, including green credit, green bonds, green medical coverage, and green investment (Li, 2023; Sang, 2024). Complementary evidence is provided by Al Mamun et al. (2022), who employ the Common Correlated Effects Pooled estimator to analyze 46 countries and find that green finance contributes to reducing carbon emissions. This result aligns with earlier work by Ren et al. (2020), who applied a VECM to account for long-run dynamics and identify a significant relationship between green finance initiatives and declining CO_2 emissions. Their results further show that green finance stimulates clean energy consumption while lowering carbon intensity. Similar results were obtained from the results of the work of Xue et al. (2022) and Taghizadeh-Hesary and Yoshino (2019). The work of Ruiz et al. (2016) on Colombia recommended that the government encourage private participation in the green finance system. Jawadi et al. (2025), by applying S-GMM and the Kinky least square methods, show that green finance contributes positively to the improvement of green industrialization in most of the developing countries. Building on this evidence, Xu and Lin (2024) observe that the influence of green finance on reducing carbon emissions in Chinese cities has strengthened over time. In addition to its environmental benefits, green finance instruments may also offer financial stability advantages. For example, Gök et al. (2025) argue that green bonds can exhibit safe-haven characteristics, meaning they remain stable or even increase in value during periods of market uncertainty while generating environmentally oriented returns.

Despite these optimistic findings, a growing body of literature questions the effectiveness of green finance in consistently promoting green growth.

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Some scholars emphasize structural weaknesses and market inefficiencies that can undermine its impact. Wang et al. (2022b), for example, employ data envelopment analysis combined with a Tobit model and find a negative relationship between green finance and ecological efficiency in China. Their results suggest that financial resources labeled as "*green*" do not always translate into effective environmental outcomes. Similarly, Adekoya et al. (2021) highlight inefficiencies in the United States green bond market, attributing them to significant price volatility that weakens the reliability of green financial instruments. Reinforcing this argument, Liu (2022) applies the Heterogeneous Autoregressive model and shows that financial market instability reduces the efficiency of green finance mechanisms in China. Also, in China, the work of He et al. (2019) shows that green finance reduces the efficiency of investments in renewable energy. These findings imply that although green finance has considerable potential, its success depends heavily on stable financial markets and strong institutional frameworks.

Several structural factors help explain these mixed outcomes. In many cases, green finance investments are unevenly distributed across regions, which limits their capacity to generate widespread environmental benefits. Tchapchet-Tchouto et al. (2022), through a study on EU countries applying the ordinary least squares method, discovered that the effects of environmental taxes vary depending on the country. When financial flows are concentrated in already developed areas, vulnerable regions like those of SSA may lack the resources necessary to adopt sustainable technologies or practices. Besides, weak implementation of green projects can reduce the environmental effectiveness of financed initiatives. Policy priorities may also create tensions between economic growth and environmental protection. Governments may sometimes favor projects that generate immediate economic returns, even if they are polluting, over green investments that offer longer-term environmental benefits. Such trade-offs between short-term economic performance and environmental sustainability can ultimately slow the transition toward green growth, as highlighted by Hatakeda et al. (2012).

These challenges are particularly pronounced in SSA, where the integration of green finance into development strategies remains limited. Many countries in the region lack comprehensive regulatory frameworks to guide green financial activities, and existing policies are often fragmented or poorly coordinated. As Khalid et al. (2024) emphasize, the absence of clear strategies, institutional incentives, and supportive financial ecosystems constrains the adoption and effectiveness of green finance mechanisms. Moreover, concerns have emerged regarding the credibility of some projects financed under the "*green*" label. In certain cases, such initiatives generate only marginal environmental benefits, thereby creating a difficult balance between economic performance and genuine environmental impact (Wang et al., 2022a).

Another structural constraint relates to the heavy dependence of green finance initiatives on international organizations and external funding sources. While international support can facilitate the launch of green projects, it also exposes them to fluctuations in global financial flows and to stringent conditionalities imposed by donors. According to Dercon (2014), such reliance may reduce the long-term stability and sustainability of green investment programs in developing economies. Taken together, these institutional, financial, and structural challenges contribute to ongoing disagreements about the effectiveness of green finance in promoting green growth within SSA. Despite the growing importance of sustainable finance globally, relatively few studies have specifically examined the relationship between green finance and green growth in this region. In this context, emerging digital financial technologies may offer new opportunities to improve the effectiveness and accessibility of green finance.

Against this background, recent research has begun to explore how financial technology (FinTech) can support the development of green finance and enhance its contribution to green growth. A growing number of studies emphasize that FinTech can strengthen green financial systems by improving financial inclusion, reducing transaction costs, and facilitating more efficient allocation of resources toward environmentally sustainable projects (Zhou et al., 2022; Wu, 2024). Empirical evidence supports this complementary relationship. For instance, Muganyi et al. (2021) analyze data from 290 Chinese cities and find that green finance significantly reduces industrial emissions, while FinTech development amplifies these environmental benefits. Similarly, Udeagha and Muchapondwa (2023) apply the CS-ARDL technique to address potential endogeneity issues and confirm that FinTech strengthens the positive impact of green finance on environmental sustainability. Nenavath and Mishra (2023) reach comparable conclusions, emphasizing that technological innovation in financial services enhances the efficiency and accessibility of green financing mechanisms. More recently, Zia et al. (2024) employ the two-step GMM estimator to control for endogeneity and demonstrate that the interaction between green finance and FinTech significantly improves environmental efficiency.

However, the role of FinTech is not entirely unambiguous. Some studies point to potential unintended consequences associated with digital financial expansion. Qin et al. (2022), for example, use a High-Dimensional Fixed Effects approach to address endogeneity concerns and find that FinTech development can indirectly increase household carbon emissions by stimulating higher levels of consumption. At the same time, their results suggest that FinTech may also encourage greener consumption patterns by facilitating access to environmentally friendly products and services. This dual effect indicates that the environmental implications of FinTech depend largely on the broader economic and regulatory environment in which it operates.

Given these mixed findings, further research is needed to better understand how FinTech can effectively complement green finance in promoting sustainable development. This need is particularly important in the context of SSA, where financial systems are still evolving and where digital financial innovations could play a crucial role in expanding access to green investment opportunities and improving the overall effectiveness of green finance in supporting green growth.

The literature remains divided on whether green finance effectively promotes green growth, with evidence ranging from optimistic to skeptical. This divergence reflects structural constraints, including unequal investment allocation, weak regulatory frameworks, and dependence on external financing. In SSA, where green finance integration into development strategies remains limited, FinTech may enhance the accessibility and effectiveness of green finance, thereby supporting green growth.

Against this backdrop, this study examines the effect of green finance on green growth and assess the moderating role of FinTech in this relationship.

We test two hypotheses: (i) green finance has a positive and statistically significant effect on green growth in SSA; and (ii) the effect of green finance on green growth is stronger at higher levels of FinTech development.

2. METHOD

This study analyzes the relationships between green growth, green finance, and FinTech within the Environmental Kuznets Curve (EKC) framework (Udeagha & Ngepah, 2023; Tufail et al., 2024; Konan & Aklobessi, 2021). Economic growth initially increases environmental degradation, especially in SSA, where renewable energy adoption remains limited (Dinda, 2004), implying a negative pressure of GDP on green growth. In contrast, green finance promotes green growth by channeling funds into sustainable infrastructure, renewable energy, and environmental projects. FinTech strengthens this process by digitizing financial flows, reducing information frictions, lowering the financial sector's carbon footprint, and expanding access to climate finance for rural communities. Supportive institutions and demographic potential further enhance these effects. The green finance is the main explanatory variable, and FinTech acts as a moderating factor. To test the EKC curve hypothesis, GDP is included. The empirical model also includes control variables and is presented as follows:

$$GG_{it} = f\left(GreenFin_{it},\ FinTech_{it},\ X_{it}\right), \qquad (1)$$

where GG_{it}, $GreenFin_{it}$ and $FinTech_{it}$ represent, respectively, green growth, green finance, and FinTech in the country i at the time t. X_{it} represents a vector of control variables. To make the variables more stable, they have been linearized. The functional model is specified as follows:

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$$lnGG_{i,t} = \delta_0 + \delta_1 lnGG_{i,t-1} + \delta_2 lnGreenFin_{it} + \delta_3 lnFinTech_{it} + \partial_j lnX_{it} + \mu_{it}, \quad (2)$$

where δ_0 represents the constant, δ_1 captures the effect of delayed green growth, δ_2 captures the effect of green finance, δ_3 captures the effect of FinTech, and ∂_j captures the effects of the different control variables (GDP, population growth, total natural resource rent, labor force, financial globalization and governance). μ_{it} represents the error terms. The models for each successive step are structured similarly to those of Udeagha and Ngepah (2023). The first model analyzes an economy without green finance and FinTech. The economy includes only control variables, including GDP. Model 1 is specified below:

$$lnGG_{i,t} = \delta_0 + \delta_1 lnGG_{i,t-1} + \partial_1 lnGDP_{it} + \partial_2 lnPOPgrow_{it} + \partial_3 lnTNatRRent_{it} + \partial_4 lnLaboForce_{it} + \partial_5 lnFiGI_{it} + \partial_6 GUV\_Index_{it} + \mu_{it}. \quad (3)$$

Model 1 above incorporates green finance and yields the second model below:

$$lnGG_{i,t} = \delta_0 + \delta_1 lnGG_{i,t-1} + \delta_2 lnGreenFin_{i,t} + \partial_1 lnGDP_{i,t} + \partial_2 lnPOPgrow_{i,t} + \partial_3 lnTNatRRent_{i,t} + \partial_4 lnLaboForce_{i,t} + \partial_5 lnFiGI_{i,t} + \partial_6 GUV\_Index_{i,t} + \mu_{i,t}. \quad (4)$$

In Model 2, FinTech is included, resulting in the third model below:

$$lnGG_{i,t} = \delta_0 + \delta_1 lnGG_{i,t-1} + \delta_2 lnGreenFin_{i,t} + \delta_3 lnFinTech_{i,t} + \partial_1 lnGDP_{i,t} + \partial_2 lnPOPgrow_{i,t} + \partial_3 lnTNatRRent_{i,t} + \partial_4 lnLaboForce_{i,t} + \partial_5 lnFiGI_{i,t} + \partial_6 GUV\_Index_{i,t} + \mu_{i,t}. \quad (5)$$

In Model 3 above, the interaction variable between green finance and FinTech is incorporated. This allows us to account for the moderating effect of FinTech on green finance. Model 4 is structured as follows.

$$lnGG_{i,t} = \delta_0 + \delta_1 lnGG_{i,t-1} + \delta_2 lnGreenFin_{i,t} + \delta_3 lnFinTech_{i,t} + \delta_4 lnGreenFin_{i,t} xFinTech_{i,t} + \partial_1 lnGDP_{i,t} + \partial_2 lnPOPgrow_{i,t} + \partial_3 lnTNatRRent_{i,t} + \partial_4 lnLaboForce_{i,t} + \partial_5 lnFiGI_{i,t} + \partial_6 GUV\_Index_{i,t} + \mu_{i,t}. \quad (6)$$

The data cover 35 Sub-Saharan African countries from 2000 to 2021. The analysis is constrained by the availability of data of the dependent variable (green growth), which is consistently reported for the selected countries only up to 2021. More recent data remain unavailable for many countries. Following Sarkodie et al. (2023), green growth, the dependent variable, is measured by the composite indicator (Table 1).

Green finance is measured by a composite index following Udeagha and Ngepah (2023), Tufail et al. (2024), and Jawadi et al. (2025). This index integrates three dimensions: environmental protection expenditures, environmental taxation, and public investment in renewable energy. These dimensions align with the objectives of green finance, which are primarily the energy transition and the fight against climate change (Zhao et al., 2023). Alternatively, FinTech is measured by the FinTech Financial Index, established according to the methodology of Banik and Roy (2023), which is constructed using a two-level principal correspondence analysis procedure. The first level synthesizes four fundamental dimensions: penetration, availability, usage, and competence. These dimensions are then aggregated at the second level to generate the composite FinTech Index, thus ensuring a robust and multidimensional measure.

In addition to these variables, six other control variables were included. Gross domestic product, used by Udeagha and Ngepah (2023), and demographics, which significantly influence economic growth according to Jawadi et al. (2025), are included in the models. Natural resource rent influences green growth (Bitassa et al., 2025), as does the labor force, a key driver of growth (Jahanger et al., 2022). Financial openness, justified by the in-

Table 1. Definition of variables and sources

Variables	Definition	Source	Mean	Standard deviation
GG	Green Growth Index (score)	FigShare (Sarkodie et al., 2023)	0.482	0.153
GreenFin	Green finance (score)	FAO/IRENA/ Ourworldindata	0.069	0.109
FinTech	FinTech (score)	FAS/FMI, WDI et UIT	0.192	0.154
GDP	GDP per capita (US$)	WDI	3.60e+10	8.06e+10
POPgrow	Population growth (%)	WDI	2.471	0.957
TNatRRent	Total rent from natural resources (US$)	WDI	11.771	10.591
LaboForce	Labor force (%15+)	WDI	66.902	11.129
FiGI	Financial globalization (score)	KOF Swiss Economic Institute	45.768	11.691
GUV_Index	Governance level (scor)	WDI	0.457	0.216

ternational origin of green funds for ASS (Chen et al., 2023), as well as the governance index (Jawadi et al., 2025), complete the list of variables.

3. RESULTS

The dynamics of green growth in SSA over the period 2000–2021 highlight an overall positive trend, albeit marked by fluctuations (Figure 1). This dynamic reflects the gradual efforts undertaken by SSA countries to integrate environmental dimensions into their development strategies, while also revealing the persistence of structural constraints hindering the consolidation of this progress. From 2000 to 2005, green growth in SSA remained moderate due to limited attention to environmental issues and uneven implementation of sustainable resource policies. Between 2006 and 2011, it slowed significantly, reaching a low point around 2010–2011 amid the global financial crisis and continued dependence on extractive sectors. From 2012 onward, green growth improved, supported by stronger international sustainability commitments, expanding green finance, and the diffusion of clean technologies. Performance was particularly strong between 2013 and 2018 as green investments consolidated. However, momentum weakened after 2019, with a sharp decline in 2020–2021 linked to the COVID-19 pandemic. Despite these shocks, the long-term trend remains positive.

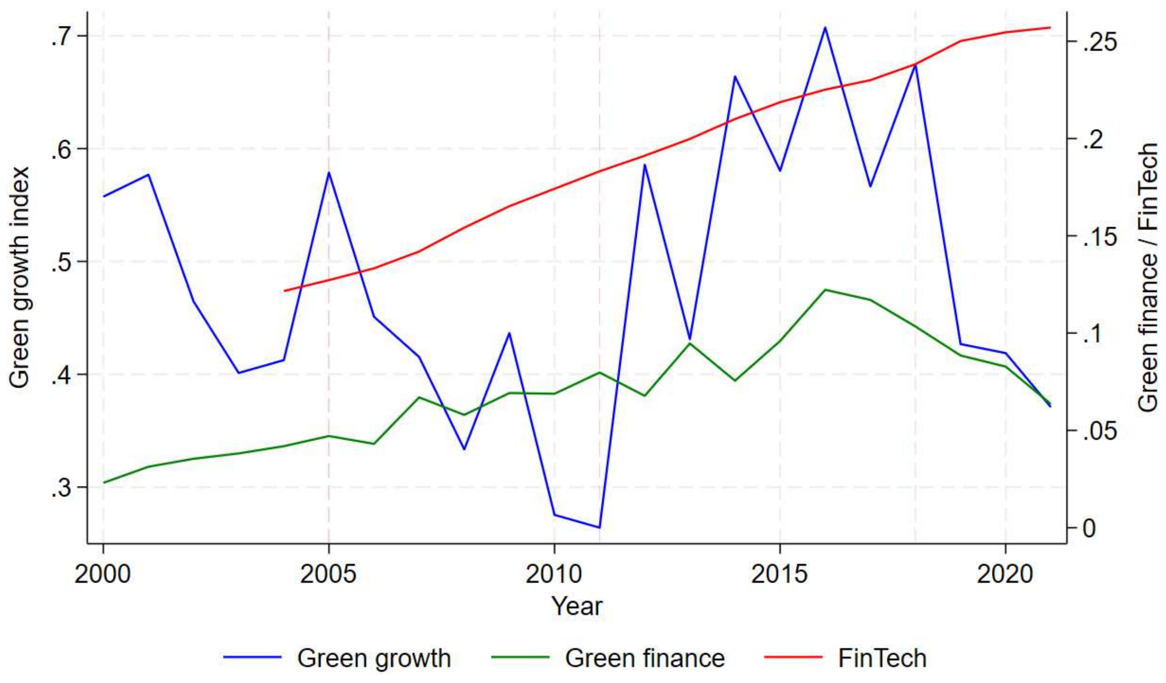

Figure 1. Dynamics of green growth, green finance, and FinTech in SSA

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Table 2. Pesaran cross-sectional dependence test

Variables	CD	CDw	CDw+	CD*
*ln*GG	70.220***	2.170**	1724.530***	2.310**
*ln*GreenFin	27.270***	0.410	772.490***	0.850
*ln*FinTech	108.170***	–3.170***	2635.500***	7.080***
*ln*GreenFin***x***FinTech	42.170***	–1.930**	1149.760***	1.360
*ln*GDP	103.730***	–2.970***	2523.160***	–0.730
*ln*POPgrow	3.040***	–0.390	1217.550***	0.380
TNatRRent	19.590***	0.030	837.860***	5.610***
*ln*LaboForce	32.670***	–1.250	1511.880***	1.110
*ln*FiGI	8.100***	2.660**	1046.340***	2.050***
GUV_Index	2.480**	–1.070	1195.490***	0.700

Note: *** $p < 0.01$, ** $p < 0.05$.

Green finance in SSA followed a generally upward trajectory. Initially weak between 2000 and 2006, it accelerated after 2007 and peaked around 2016 amid stronger global climate commitments. Although growth slowed afterward due to macroeconomic constraints, levels remained above those of the late 2000s. FinTech expanded steadily from 2004 to 2021, reflecting technological progress, improved digital infrastructure, and broader financial inclusion.

To test the cross-sectional dependence (Table 2), we applied the Pesaran test (2015, 2021), which distinguishes between weak and strong cross-sectional dependence. Weak dependence occurs when the interdependence tends toward zero as the number of cross-sections increases, while strong dependence exhibits stable correlations. The null hypothesis assumes a weak or zero cross-sectional correlation, as opposed to the alternative hypothesis of a strong cross-sectional dependence. Pesaran CD test (2015; 2021) shows the presence of highly significant cross-sectional dependence (Table 2). The CDw+ test rejects *H0* for all variables and confirms the presence of cross-sectional dependence. In contrast, the CDw and CD* tests show the presence of cross-sectional dependence for half of the variables. Our results reject the null hypothesis, indicating significant cross-sectional dependence among the SSA countries, thus supporting the use of second-generation unit root tests.

The second-generation IPS tests of Im et al. (2003) and the CIPS of Pesaran (2007) were used under the null hypothesis (*H0*) of the presence of a unit root against the alternative hypothesis (*Ha*) of non-stationarity. Unit root tests indicate that some variables are stationary in levels, I(0), while others become stationary after first differencing, I(1). This mixed order of integration does not exclude the possibility of a long-run relationship, which justifies conducting a cointegration test (Table 3). The Kao et al. (1999) cointegration test was applied with the null hypothesis (*H0*) of no cointegration against the alternative (Ha) of a cointegrating relationship.

The results reported in Table 3 reject *H0*, confirming the existence of a stable long-term relationship among the variables. Because several variables in this study are multidimensional indices, potential issues such as endogeneity, autocorrelation, measurement errors, reverse causality, and dynamic persistence may arise. To address these concerns, GMM in its system form (System-GMM) is adopted, as it can simultaneously manage endogeneity, serial correlation, and model dynamics through the use of internal instruments. Compared with standard GMM, System-GMM offers greater efficiency. Carrasco and Florens (2000) highlight three main advantages: it produces consistent and efficient estimates even with lagged variables, accounts for unobserved heterogeneity, and remains robust in the presence of multicollinearity.

The One-Step System-GMM estimator is used as the main approach because it combines equations in first differences and levels, controls for unobserved individual effects, and reduces bias linked to the lagged dependent variable (Roodman, 2009). This method is well-suited to panels with many cross-sections but relatively few time periods (Blundell & Bond, 1998). For robustness, the Two-Step System-GMM estimator with small-sample correction is also applied.

Table 3. Unit root test

Variables Z–t–tilde–bar	IPS unit root tests (Im et al., 2003)		CIPS unit root tests (Pesaran, 2007)	
	Decision	CIPS	Decision	
*ln*GG	–8.9440***	I(0)	–3.681***	I(0)
*ln*GreenFin	–7.2699***	I(0)	–3.173***	I(0)
*ln*FinTech	–8.1303***	I(1)	–2.090**	I(0)
*ln*GreenFin**x**FinTech	–4.3233***	I(0)	–1.957**	I(0)
*ln*GDP	–10.9413***	I(1)	–3.947***	I(1)
*ln*POPgrow	–6.7109***	I(1)	–3.186 ***	I(1)
TNatRRent	–3.0935***	I(0)	–2.916***	I(0)
*ln*LaboForce	–8.9513***	I(1)	–3.026***	I(1)
*ln*FiGI	–2.0959**	I(0)	–2.903**	I(1)
GUV_Index	–1.5919**	I(0)	–2.705**	I(0)

Kao cointegration test

Models	t-statistics
lnGG = f(lnGDP, lnPOPgrow, TNatRRent, lnLaboForce, lnFiGI, GUV_Index)	–11.9293***
lnGG = f(lnGreenFin, lnGDP, lnPOPgrow, TNatRRent, lnLaboForce, lnFiGI, GUV_Index)	–11.910***
lnGG = f(lnGreenFin, lnFinTec, lnGDP, lnPOPgrow, TNatRRent, lnLaboFRate, lnFiGI, GUV_Index)	–8.8471***
lnGG = f(lnGreenFin, lnFinTec, lnGreenFin**x**FinTech, lnGDP, lnPOPgrow, TNatRRent, lnLaboFRate, lnFiGI, GUV_Index)	–8.8130***

Note: *** $p < 0.01$, ** $p < 0.05$.

Table 4 presents the econometric results of models estimated using a dynamic approach to analyze the effects of variables of interest and macroeconomic variables on green growth in SSA. Model 1 presents a baseline specification, while Models 2 and 3 successively introduce green finance and FinTech, and Model 4 incorporates their interaction to capture their combined effects. The results indicate that the introduction of green finance in Models 2 to 4 has a positive, statistically significant effect on green growth at the 5% level. In Model 4, the most comprehensive, a 1% increase in green finance improves green growth by 5.63%. This suggests that the development of financial instruments dedicated to green projects significantly improves both environmental and economic performance. The relatively high coefficients confirm that green finance constitutes an important strategic lever for ecological transition in developing economies, particularly in Sub-Saharan Africa. The first hypothesis, which states that green finance, by providing financial resources to sustainable projects, positively affects green growth, is then verified.

FinTech is introduced in Models 3 and 4. In both Models, the coefficients associated with FinTech are positive and highly significant, indicating that financial technologies play a constructive role in promoting green growth. The results suggest that a 1% increase in FinTech leads to improvements of 7.23% and 7.62% in green growth, respectively. Model 4 also highlights a moderating effect through the interaction between green finance and FinTech, which is positive and significant at the 5% level, with a marginal value of 0.22%. This finding indicates that the combined development of green finance and financial technologies strengthens their contribution to green growth, confirming the second hypothesis.

Regarding the control variables, GDP per capita shows a negative and highly significant effect on green growth across all models. Specifically, a 1% increase in GDP per capita leads to a decrease in green growth ranging from 0.58% to 1.894%. In contrast, population growth significantly enhances green growth in Sub-Saharan Africa. The coefficient increases from 0.484% in Model 1 to 2.292% in Model 4, suggesting that the demographic effect becomes stronger when green finance and FinTech are included in the analysis. This highlights the growing importance of population dynamics in models incorporating financial factors.

Total natural resource rents exhibit a negative and statistically significant coefficient in all models, ranging from -0.018% to -0.028% at the 1% significance level. This indicates that increased reliance on natural resource exploi-

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Table 4. Estimation of the effects of green finance, FinTech, and their interaction on green growth in SSA

Variables	Green growth in SSA (dependent variable)			
	Model 1	Model 2	Model 3	Model 4
L.*ln*GG	–0.0390	–0.047	0.108	0.064
	(0.045)	(0.048)	(0.119)	(0.148)
*ln*GreenFin		4.974**	8.482**	5.631**
		(2.273)	(3.483)	(2.234)
*ln*FinTech			7.264***	7.625***
			(2.792)	(2.774)
*ln*GreenFin***x***FinTech				0.216**
				(0.087)
*ln*GDP	–0.5840**	–0.694**	–1.442**	–1.894***
	(0.265)	(0.321)	(0.594)	(0.722)
*ln*POPgrow	0.4844**	0.650**	1.669**	2.292***
	(0.217)	(0.288)	(0.653)	(0.846)
TnatRRent	–0.0230***	–0.018***	–0.028***	–0.027***
	(0.008)	(0.006)	(0.010)	(0.009)
*ln*LaboFRate	1.0721***	1.592**	3.510**	6.472***
	(0.413)	(0.718)	(1.409)	(2.459)
*ln*FiGI	1.9122***	1.754***	1.683**	2.118***
	(0.681)	(0.623)	(0.679)	(0.793)
GUV_Index	–2.2879***	–2.039***	–4.241**	–4.918***
	(0.856)	(0.724)	(1.655)	(1.801)
Constant	1.7624	2.023	10.426**	5.863**
	(2.538)	(2.535)	(4.945)	(2.916)
Observations	735	735	611	611
Number of countries	35	35	35	35
Number of instruments	10	14	12	17
AR (2) *p*-value	0.358	0.407	0.427	0.670
Sargan test *p*-value	0.061	0.100	0.549	0.703

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

tation reduces green growth. Conversely, labor force participation contributes positively and significantly across all models. Financial openness also shows a positive and significant effect, suggesting that greater financial integration facilitates access to international capital, encourages green investment, and supports environmentally sustainable technologies. Governance quality is another key determinant, as poor governance negatively and significantly affects green growth.

Diagnostic tests confirm the robustness of the estimations. AR(2) *p*-values range from 0.358 to 0.670, indicating no second-order autocorrelation. The Sargan tests confirm the validity of the instruments, supporting the reliability of the System-GMM One-Step estimates. However, the lagged green growth variable is not statistically significant, suggesting limited persistence. Consequently, a System-GMM Two-Step approach is used as a robustness check, and the consistency of results across methods strengthens the credibility of the empirical findings.

The robustness check results using an alternative specification of the System-GMM Two-Step (Table 5). The results obtained from these estimations largely confirm the previous conclusions. Unlike previous estimations, the coefficient of the lagged term of green growth is highly significant across all specifications. This significance confirms the dynamic nature of the green growth process. The econometric tests generally demonstrate the significance and validity of the estimations. Consequently, the AR(2) tests show non-significant *p*-values, indicating the absence of second-order autocorrelation. The Sargan and Hansen tests are satisfactory in the most comprehensive models, and the number of instruments is well-managed relative to the number of countries.

Table 5. Financial innovation and green growth (robustness check with System-GMM Two-Step)

Variables	Green growth in SSA (dependent variable)			
	Model 1	Model 2	Model 3	Model 4
L.lnGG	−0.2875***	−0.2981**	0.5352***	0.4227**
	(0.034)	(0.118)	(0.163)	(0.200)
lnGreenFin		7.9420**	5.4305***	3.4892**
		(3.157)	(1.436)	(1.459)
lnFinTech			4.9608***	4.3608***
			(1.604)	(1.657)
lnGreenFin**x**FinTech				0.0773**
				(0.037)
lnGDP	−0.6234***	−1.2341***	−1.0366***	−1.0758***
	(0.204)	(0.376)	(0.261)	(0.290)
lnPOPgrow	0.4373	0.8229	1.2087***	1.2283***
	(0.372)	(0.737)	(0.313)	(0.337)
TnatRRent	−0.0579***	−0.0806**	−0.0254***	−0.0236**
	(0.020)	(0.038)	(0.008)	(0.011)
lnLaboForce	−0.1973	−0.2471	2.0363**	2.2075**
	(0.359)	(0.910)	(0.796)	(0.882)
lnFiGI	3.4066***	5.7999***	1.4132***	1.4124***
	(1.154)	(2.239)	(0.455)	(0.508)
GUV_Index	−6.7111**	−10.8719**	−3.6016***	−3.5730***
	(2.856)	(5.160)	(1.194)	(1.353)
Constant	4.6561*	11.2693*	9.2277***	9.1506***
	(2.720)	(6.258)	(3.210)	(3.435)
Observations	735	735	611	611
Number of countries	35	35	35	35
Number of instruments	13	14	15	15
AR (2) p–value	0.255	0.498	0.080	0.122
Sargan test *p*-value	0.000	0.039	0.246	0.137
Hansen test *p*-value	0.011	0.359	0.428	0.239

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

The robustness check using an alternative System-GMM Two-Step specification (Table 5) largely confirms the previous findings. Unlike earlier estimations, the coefficient of the lagged green growth term is highly significant across all specifications, confirming the dynamic nature of the green growth process. Diagnostic tests support the validity of the estimations: AR(2) tests show non-significant *p*-values, indicating the absence of second-order autocorrelation. The Sargan and Hansen tests are satisfactory in the most comprehensive models, and the number of instruments remains well controlled relative to the number of countries.

The robustness results show that green finance has a positive and significant impact on green growth in all models. Although the coefficients are slightly smaller, their sign and significance remain unchanged, confirming the stability of the green finance effect. FinTech also maintains a positive and highly significant influence. Moreover, the interaction between green finance and FinTech remains positive and significant, indicating that FinTech strengthens the effectiveness of green finance in promoting green growth. Macroeconomic variables display consistent patterns. GDP shows a negative and highly significant effect in all models, supporting the EKC hypothesis. The labor market becomes positive and significant in Models 3 and 4, highlighting its contribution when financial and technological conditions improve. Financial openness remains positive and highly significant, facilitating the diffusion of green investment in Sub-Saharan Africa, while poor governance continues to exert a significant negative effect on green growth.

The robustness of the results is confirmed using an alternative System-GMM Two-Step specification (Table 5). Marginal predictions and conditional marginal effects from the econometric

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model, helping to visualize the statistical significance of the estimated relationships, are presented (Figure 2). Figure 2a shows a linear and increasing relationship between FinTech and green growth. The prediction curve crosses the zero line at approximately 0.27, indicating a zone of statistical uncertainty where the confidence interval includes non-significant effects. Beyond this threshold, the relationship becomes positively significant and continues to increase. A similar pattern appears for green finance (Figure 2b), although the effect emerges earlier, around 0.21. The prediction curve displays a steadily increasing slope, indicating a consistently positive and robust relationship across the entire range of values. This dynamic suggests that green investments generate positive externalities that support green growth.

Figure 2c presents the marginal effect of green finance on green growth conditional on FinTech, which forms the core of the theoretical argument. The marginal effect curve shows a shallow but positive slope, confirming technological complementarity between green finance and financial digitalization. As the financial ecosystem becomes more digital, the impact of additional green finance on green growth strengthens. Importantly, the lower bound of the confidence interval remains above zero, indicating strong statistical significance of the interaction effect. FinTech therefore acts as a lever that improves the marginal efficiency of green investments and reinforces the ecological transition confirming our second hypothesis.

To assess the stability of instrumental variable estimates under endogeneity, we applied the Kinky Least Squares (KLS) sensitivity test (Kripfganz & Kiviet, 2021). This approach progressively restores correlation between the endogenous variable and structural residuals by varying the endogeneity parameter (ρ) and estimating the interaction coefficient for each value. The tests indicate positive

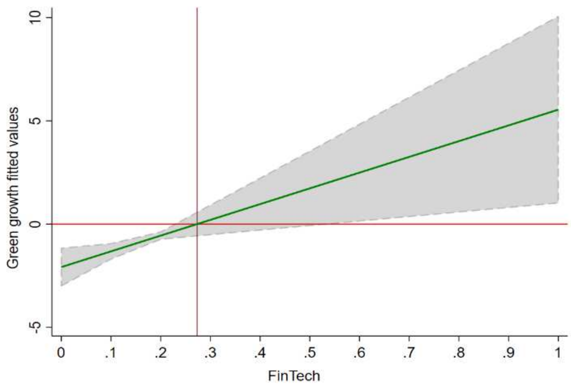

Figure 2a. Marginal effect of FinTech development

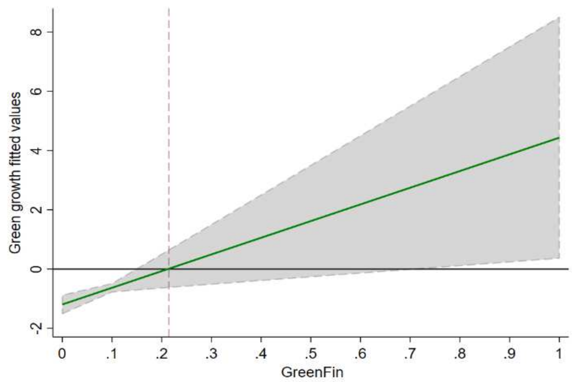

Figure 2b. Marginal effect of green finance development

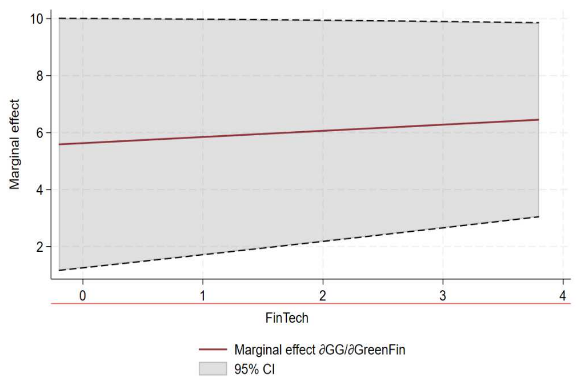

Figure 2c. Marginal effect of green finance conditional on FinTech

Figure 2. Graphical analysis of marginal effects

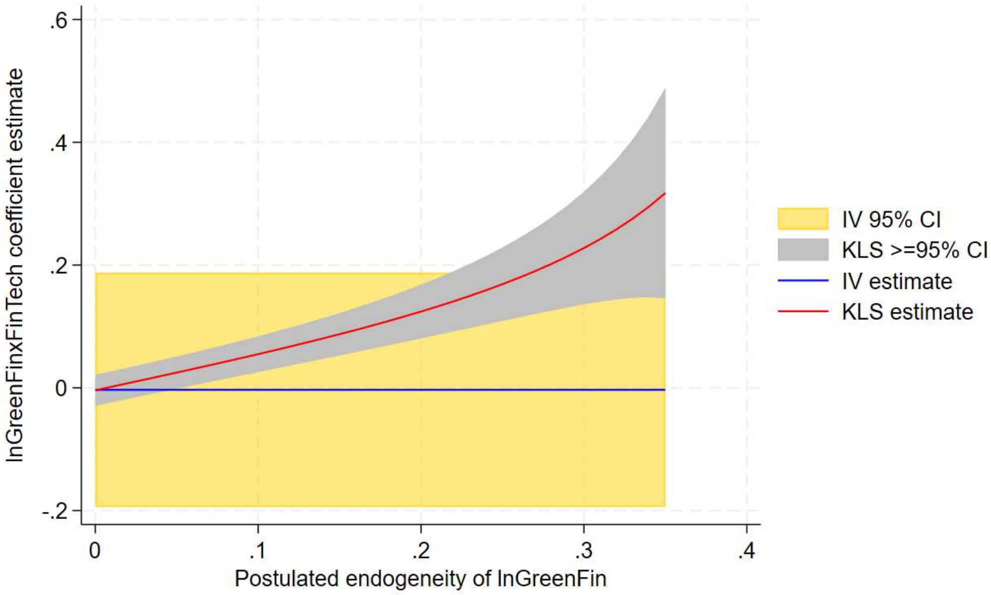

Figure 3. Sensitivity test to postulated endogeny

and moderate endogeneity (ρ ∈ [0, 0.35]). Figure 3 shows that the KLS estimates remain close to the IV benchmark with limited variance, confirming the robustness of the interaction effect.

4. DISCUSSION

The results of this work highlight the backbone role of green financial mechanisms and FinTech in the dynamic towards green growth, while revealing the importance of macroeconomic factors specific to sub-Saharan African economies. The positive and significant effect of green finance on green growth corroborates several previous studies emphasizing the importance of sustainable financial mechanisms. Tufail et al. (2024) showed that green finance accelerates green growth in OECD countries, while Udeaghha and Ngepah (2023) identified a similar positive contribution in BRICS countries. Likewise, Oanh (2023), Al Mamun et al. (2022), and Xu et al. (2023b) highlighted the role of green finance in promoting sustainable economic development. Other studies, such as Xu and Lin (2024) and Zhao et al. (2024), indicate that green finance contributes to reducing greenhouse gas emissions and improving environmental performance. As for Taghizadeh-Hesary and Yoshino (2019), green financial instruments promote the financing of low-carbon projects and also reduce financing constraints. Similarly, Xue et al. (2022) emphasize that green financial development significantly reduces CO_2 emissions. Yang et al. (2021) also emphasize that green finance supports high-quality economic growth. However, some studies report contrasting results. Wang et al. (2022b) found a negative relationship between green finance and environmental efficiency in China, while Adekoya et al. (2021) identified inefficiencies in the green bond market in the United States. These discrepancies may be explained by market volatility, regulatory constraints, and the stringent conditions attached to some green financial instruments, which may discourage long-term investments. Zhang et al. (2021) further argued that green credit policies may stimulate short-term financing but discourage long-term investment due to their restrictive nature.

In the context of SSA, green finance supports environmentally friendly initiatives by financing projects aimed at reducing greenhouse gas emissions and combating climate change. These instruments contribute to the creation of a greener economic environment, reduce environmental degradation, and support the implementation of sustainable projects, including agroecology, sustainable forestry, and renewable energy development. The involvement of international development partners further

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strengthens these efforts and promotes long-term sustainable growth.

The positive and significant impact of FinTech confirms the growing importance of digital innovations in supporting green growth. Financial technologies facilitate financial inclusion, reduce transaction costs, and improve access to financial services, thereby encouraging investments in green projects. Their role becomes particularly important in economies where traditional financial systems remain underdeveloped. These findings are consistent with the work of Zhou et al. (2022), who argue that FinTech-enhanced green finance plays a key role in promoting green growth. Similarly, Nenavath and Mishra (2023) found that FinTech strengthens the positive environmental impact of green finance, while Muganyi et al. (2021) showed that the development of FinTech positively influences green investment initiatives.

The positive interaction between green finance and FinTech confirms their complementarity in promoting green growth. FinTech acts as a dynamic channel that facilitates financial transactions, reduces information asymmetries, and strengthens financial inclusion. In SSA, where sustainable development initiatives such as climate change mitigation, agroecology, and natural resource management are gaining importance, financial technologies help connect financial institutions with stakeholders engaged in environmental activities. Furthermore, FinTech contributes to removing barriers to green finance by improving access to green credit and directing financial resources toward environmentally responsible investments. By expanding financing channels, improving the financial environment, and reducing transaction costs, FinTech strengthens financial support for green projects and promotes structural transformation toward greener economic systems (Jawadi et al., 2025; Ali, 2026).

The negative effect of GDP per capita on green growth is consistent with the EKC hypothesis (Dinda, 2004). In many Sub-Saharan African countries, economic growth is still associated with resource-intensive industrialization, increased energy consumption, and growing ecological pressures. Similar findings have been reported by Udeaghha and Muchapondwa (2023) and Udeaghha and Ngepah (2023). The positive effect of population growth can be interpreted in light of the concept of the demographic dividend. When the proportion of the working-age population increases relative to the dependent population, this can generate significant economic opportunities if appropriate policies are implemented. In the context of the SSA, a large working-age population can promote the adoption of clean technologies and support green growth. Our results are consistent with those of Bloom and Williamson (1998) but contradict those of Weber and Sciubba (2019). The negative effect of natural resource rent also reflects the presence of a resource curse phenomenon in SSA, where resource extraction often leads to environmental degradation rather than sustainable development. This result is consistent with Udeaghha and Ngepah (2023) and Xu (2022).

Conversely, the positive contribution of labor force participation highlights the importance of human capital in supporting green growth. A dynamic labor market promotes technological innovation, facilitates the diffusion of environmentally friendly practices, and strengthens the effectiveness of green investments. Ahakwa et al. (2023) similarly identified human capital as a key factor in promoting environmental sustainability. Financial openness also plays a significant role by facilitating access to international capital and concessional financing dedicated to green projects. In SSA, where a large share of green project financing comes from international organizations, financial integration promotes the transfer of clean technologies (Ali, 2021), the financing of green infrastructure, and the adoption of international environmental standards (Chen et al., 2023). Finally, governance quality emerges as a crucial determinant of green growth. Weak institutional frameworks and poor governance can hinder the effective management of natural resources and limit the implementation of environmental policies. Previous studies, such as Jawadi et al. (2025) and Bitassa et al. (2025), have also demonstrated that strong governance structures, including corruption control and political stability, are essential for achieving sustainable development and green growth.

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CONCLUSION

This study investigates the role of green finance in promoting green growth in SSA and examines the moderating contribution of FinTech to this relationship. To address potential endogeneity concerns, the analysis employs the System-GMM One-Step estimator, while the two-step estimator is used to verify the robustness of the findings. The results reveal that green finance exerts a significant positive effect on green growth across the region. Besides, FinTech strengthens the positive influence of green finance by improving financial inclusion, reducing transaction costs, enhancing transparency, and facilitating access to sustainable investment opportunities. These findings confirm the complementary roles of green finance and FinTech in advancing environmentally sustainable development in SSA.

The study concludes that strengthening green finance frameworks and promoting FinTech innovation are essential for achieving sustainable and resilient economic growth in the region. Policymakers should establish supportive regulatory environments that facilitate the development of green financial instruments and integrate sustainability criteria into investment decisions. Greater emphasis should also be placed on renewable energy investment, green innovation, and market-based mechanisms such as green bonds, carbon taxes, and emissions trading schemes to accelerate the transition toward low-carbon development. Future research may further explore the transmission channels linking green finance, FinTech, and green growth in SSA.

AUTHOR CONTRIBUTIONS

Conceptualization: Kodjo Assogba, Essossinam Ali.
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Formal analysis: Kodjo Assogba, Essossinam Ali.
Investigation: Kodjo Assogba.
Methodology: Kodjo Assogba, Essossinam Ali.
Project administration: Kodjo Assogba, Essossinam Ali.
Software: Kodjo Assogba.
Supervision: Essossinam Ali.
Validation: Kodjo Assogba, Essossinam Ali.
Visualization: Kodjo Assogba, Essossinam Ali.
Writing – original draft: Kodjo Assogba, Essossinam Ali.
Writing – review & editing: Kodjo Assogba, Essossinam Ali.

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