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Energy transition in Sub-Saharan Africa: The role of banking sector development and debt sustainability

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Abstract: This study examines the role of banking sector development and external debt in the clean energy (CE) transition across 33 SSA countries from 2000 to 2020, using a two-step system GMM. The baseline linear results show that banking sector development negatively affects the CE transition, whereas external debt has a positive independent association. However, a nonlinear estimation indicates that the negative effect of banking sector development on CE reverses after a threshold estimated at 42% of GDP, establishing a U-shaped nexus between the variables. Furthermore, a joint-effect analysis shows that the nexus becomes increasingly negative when both bank private-sector credit and external debt expand simultaneously. Finally, GDP per capita, money supply, and population growth are positively associated with CE, while carbon emissions are negatively linked to CE. Therefore, although both bank private-sector credit and external debt are critical for the CE transition in SSA, their roles are independent and substitutive.

Keywords: banking sector development; clean energy transition; external debt; fossil energy; EKC hypothesis; renewable energy consumption

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1. Introduction

Clean energy (CE) adoption has become a defining global imperative amid escalating climate challenges and energy poverty. Energy augments the productive capacity of the factors of production, improving the quality of economic and human development (Belke et al., 2010). The lack of a reliable energy supply therefore constrains economies' productive sectors, limiting economic prospects and deepening social exclusion (Chireshe, 2020).

The global policy shift from traditional energy sources to clean renewable alternatives is especially relevant and critical from Sub-Saharan Africa's (SSA) perspective, given the region's climate vulnerability and growing energy deficit, despite its abundant clean renewable energy resources (Cai et al., 2025). The International Renewable Energy Agency's (IRENA, 2024) report indicates that over 600 million people in SSA still lack access to electricity. Meanwhile, Ebhota and Tabakov (2024) note that renewable energy (RE) sources in SSA provide about 11,000 GW of exploitable generating capacity, enough to replace fossil consumption in the region fully. Regrettably, the regional deficit in electricity access alone constitutes about 80% of the world's population without electricity, highlighting the urgent need for the region to adopt clean energy.

Adopting clean renewable energy diversifies energy sources, protecting consumers from price volatility and supply shocks characteristic of fossil energy, and improving energy access and security. Additionally, clean energy adoption reduces carbon emissions, lessening climate challenges and health hazards associated with greenhouse gas emissions. This underscores the critical role of the clean energy transition in

improving SSA's Environmental, Social, and Governance (ESG) performance and aligning with global sustainability goals.

While the positive externalities of clean energy consumption are well documented, clean renewable energy projects in SSA remain heavily underfunded. Various energy reports, including IRENA (2024), Ebhota and Tabakov (2024), and Cai et al. (2024), have attributed the clean energy deficit in SSA to inadequate funding for RE infrastructure, as both RE sources and technology are readily available. In light of this, banking sector development and external debt have emerged as critical determinants influencing clean energy adoption. External debt financing has been closely linked to RE projects because of the latter's huge upfront capital requirement, which may potentially crowd out other sectors of domestic bank financing.

Extant literature on the financial development-RE consumption nexus suggests inconclusive outcomes, owing to the contrasting results of empirical studies. For example, while Onuoha et al. (2023) and Appiah et al. (2023) report a negative relationship between financial development and RE, the empirical findings of studies by Diallo and Ouoba (2023), Chireshe (2021), Nyeadi (2023), and Anton and Nucu (2020) find a positive association between the variables.

Despite this progress, current studies are limited by their predominant reliance on linear frameworks, overlooking potential curvilinear dynamics between financial development and clean RE adoption. This oversight fails to account for potential thresholds or turning points that curvilinear analysis would reveal, in line with the Environmental Kuznets Curve (EKC) hypothesis. In this context, we agree with Fan et al. (2025) that understanding how financial development affects RE adoption has moved beyond a linear perspective. Additionally, while Saleem-Jabari et al. (2022) and Onuoha et al. (2023) examined the independent effects of external debt and public debt, respectively, on RE consumption, they largely overlooked the potential signaling or constraining role of external debt in combination with financial development. This study closes the gaps highlighted above by examining whether the roles of banking sector development and external debt stock are complementary or substitutive in relation to SSA's clean energy adoption, using both curvilinear and linear methods.

This study provides two key contributions to the literature. First, it provides a curvilinear perspective on the financial development-clean energy nexus, an approach that has not been previously explored, to the best of our knowledge. Second, the study is the first to investigate the joint effects of banking sector development and external debt on CE adoption, with external debt deployed in a moderating role. This integrated perspective allows a deeper assessment of how financial development and fiscal positioning jointly shape the region's progress toward the clean energy transition.

The remaining part of this paper is organized into the following sections: Section 2 deals with the literature review, while Section 3 focuses on the methods to achieve the objectives of the paper; Section 4 discusses the results, while Section 5 summarizes the findings, draws conclusions, and provides policy prescriptions based on the findings.

2. Literature Review

2.1. Theoretical Literature

2.1.1. Finance and clean renewable energy adoption

The relationship between financial development and RE consumption can be underpinned by several theories, including the finance-led growth theory, growth-led finance theory, the neutrality theory, and the disruptive theory. Schumpeter's (1911) supply-leading hypothesis explains that when savings are efficiently mopped up and allocated through financial intermediation to productive deficit users, they generate expansion and growth in the real sector. This increases the demand for sustainable energy to support further industrial expansion, production, transport services and household

consumption. This suggests a positive connection between financial development and CE consumption.

The McKinnon (1973) and Shaw (1973) financial liberalization theory argues that a repressed financial sector, through dictated credit policies, deliberate interest rate interventions, and tight reserve ratios, constrains economic growth and limits funding for RE projects. Thus, a liberalized financial sector frees the sector from government impediments that hinder capital flow to the real sector and drive growth and clean energy demand. On the other hand, the demand-following hypothesis pioneered by Robinson (1952) postulates that investment through entrepreneurial activities generates economic growth and employment, which in turn creates more savings. Higher savings lead to credit creation, which underpins financial intermediation and banking sector development, fostering RE adoption. In contrast, Minsky (1974) argues that increased financial development eventually leads to macroeconomic fluctuations, distorting savings and lending, and hampering capital flow to RE projects.

The theories discussed so far explain a linear association between financial development and RE adoption. However, the relationship under review could be nonlinear and mimic the EKC argument. The traditional EKC theory postulates an inverted U-shaped relationship between income level and environmental quality. The theory explains that countries initially experience brown growth, leading to a decline in environmental quality. However, at some point, countries pursue green growth to control environmental degradation. Building on the traditional EKC argument, we can infer that the relationship between financial development and RE consumption may follow a U-shaped curve. In the early stages of financial development, risk-averse banks tend to favor brown, low-risk fossil energy lending. However, as economies and their banking systems mature, financial development tends to promote green (RE) investment. This study adopts the EKC hypothesis to explore the evolving role of the banking sector in facilitating RE adoption.

2.1.2. External debt stock and clean energy adoption

According to Saleem-Jabari et al. (2022), a country's debt level is expected to negatively affect clean energy consumption, in line with debt overhang theory, through three channels. First, when a country's debt level becomes unsustainably high, it distorts the economy and erodes real income. This leads rational economic actors to be reluctant to commit further resources to high-risk investments like clean RE projects. Second, unsustainable debt levels seep into fiscal policy. This manifests in high, multiple tax systems as governments try to raise more revenue to service debt. Under such tight fiscal regimes, savings decrease, undermining CE financing. Third, high debt levels heighten default risk and increase the cost of capital, threatening CE investment.

However, Cai et al. (2024) argue that the initial capital investment required for RE generation is high, underscoring the critical role of external credit in complementing domestic bank credit to fund RE infrastructure. Moreover, sustainable development theory suggests that governments could secure external loans to fund clean energy projects, advancing environmental and social goals through reduced carbon emissions and improved energy security. From these perspectives, external debt could promote the clean energy transition by addressing critical funding gaps.

2.2. Empirical Literature Review

This section contains a review of the extant empirical literature on the finance–clean energy nexus. Several empirical studies have explored the finance–clean energy nexus, offering diverse findings across regions. For instance, Anton and Nucu (2020) investigated the nexus in Europe using the Fixed Effects method, and their results indicated a positive relationship across all financial development proxies. Similarly, Shahbaz et al. (2021), using data from 34 upper middle-income countries and employing the Fully Modified Ordinary Least Squares (FMOLS) method, found a positive association between financial

development and RE consumption. Consistent findings were reported by Mukhtarov et al. (2022), Mukhtarov et al. (2020), Saleem-Jabari et al. (2022), and Samour et al. (2022), using data outside SSA and applying estimation techniques such as Auto-Regressive Distributed Lag (ARDL), Vector Error Correction Model (VECM), and Fixed Effects. In contrast, Wang et al. (2021), using ARDL-Pooled Mean Group (PMG) estimation on data from China, found a negative relationship between financial development and RE adoption.

Focusing on SSA, Diallo and Ouoba (2023) found a positive nexus between financial development and RE consumption, employing AMG and Common Correlated Effects Mean Group (CCEMG). Chireshe (2021), using Fixed-effect estimation, and Nyeadi (2023), using PMG-ARDL, both reported similar positive findings. However, Appiah et al. (2023) and Onuoha et al. (2023), who analyzed SSA data using Panel Quantile ARDL and Feasible Generalized Least Squares (FGLS), respectively, found a negative relationship between financial development and RE consumption.

The above empirical literature on financial development-renewable energy studies has largely focused on linear models, notably neglecting the potential curvilinear complexities in their empirical analyses. Additionally, the joint effect of bank private-sector credit and external credit on clean energy consumption has not been explored. Furthermore, parameter estimates in the studies on the nexus under review have been obtained using techniques that do not fully account for endogeneity arising from omitted variables, reverse causality, and measurement error. These omissions are serious, given the mixed results of previous empirical studies. The mixed findings underscore the complexity of the finance–clean renewable energy relationship and highlight the need for further research methods that incorporate additional dimensions, such as external debt moderation and nonlinear dynamics, utilizing the two-step system GMM to address the problems of endogeneity and persistence that previous studies ignored.

Based on the theoretical foundations and the existing gap identified in the literature, we propose to empirically test the following hypotheses.

H1: There is a positive relationship between banking sector development and energy transition.

H2: There is a U-shaped relationship between banking sector development and energy transition.

H3: There is a relationship between external debt stock and clean energy transition.

H4: External debt negatively moderates the banking sector development-CE adoption nexus

3. Data and Methods

The study examines the role of banking sector development and external debt in the energy transition by utilizing panel data from 33 SSA countries spanning the period 2000 to 2020.

3.1. Model specification

Following empirical studies by Anton and Nucu (2020) and Ntow-Gyamfi et al. (2020), the study proposes that clean energy consumption is a function of the determinants expressed in the models below:

$$CET_{it} = \delta_1 CET_{it-1} + \delta_2 BSD_{it} + \delta_3 EDS_{it} + \delta_4 INV_{it} + \delta_5 InGDP_{it} + \delta_6 POP_{it} + \delta_7 MS_{it} + \delta_8 CO2_{it} + \delta_9 GCrisis_t + a_i + b_t + c_{it} \quad (1)$$

$$CET_{it} = \pi_1 CET_{it-1} + \pi_2 BSD_{it} + \pi_3 BSD^2{}_{it} + \pi_4 EDS_{it} + \pi_5 INV_{it} + \pi_6 InGDP_{it} + \pi_7 POP_{it} + \pi_8 MS_{it} + \pi_9 CO2_{it} + \pi_{10} GCrisis_t + \theta_i + u_t + \varepsilon_{it} \quad (2)$$

$$CET_{it} = \lambda_1 CET_{it-1} + \lambda_2 BSD_{it} + \lambda_3 BSD^2{}_{it} + \lambda_4 EDS_{it} + \lambda_5 (BSD * EDS)_{it} + \lambda_6 INV_{it} + \lambda_7 InGDP_{it} + \lambda_8 POP_{it} + \lambda_9 MS_{it} + \lambda_{10} CO2_{it} + \lambda_{11} GCrisis_t + q_i + k_t + v_{it} \quad (3)$$

CET represents the clean energy transition; BSD and BSD^2 denote banking sector development and the square term of banking sector development, respectively; EDS refers to external debt stock, lnGDP represents the log of per capita income, INV denotes domestic investment, BSD*EDS is an interaction term between banking sector development and external debt, POP is population growth, MS denotes money supply, while CO2 indicates carbon emissions. GCrisis is a dummy variable for global crisis periods. These variables have been selected based on their established relationships in the empirical literature.

Banking sector development and external debt stock are the two main proposed determinants of the clean energy transition in this study. The banking sector could promote the green transition or entrench fossil consumption, depending on the level of economic and financial development, according to the EKC theory. Also, the inclusion of external debt in the model serves two purposes. First, it serves as a potential financing source that can either induce or hinder clean energy adoption. Second, it is utilized as a moderator in the bank finance-clean energy nexus to explore how risk-averse banks respond to clean energy investment in SSA, amid rising external debt levels. Additional variables, namely income level, population growth, money supply, domestic investment, and CO2 emissions, are incorporated as control factors based on insights from existing literature.

Empirical studies on the finance- renewable energy nexus have often utilized GDP as the conventional measure of a country's wealth (see Anton and Nucu, 2020; Rahman et al., 2023; Nawaz & Rahman, 2023; Nyeadi, 2023). Theoretically, advanced sustainable development leads to increased demand for clean energy. Additionally, factors such as population growth, money supply, and investment variables have been heavily used in the literature (see Rahman et al., 2023; and Chireshe, 2021) due to their importance in affecting clean energy consumption. Moreover, the study includes domestic investment to gauge domestic efforts towards clean energy strategies and environmental sustainability. Furthermore, the study model adopts CO2 emissions as one of its controls, in line with Nyeadi (2023). According to the EKC hypothesis, early-stage growth leads to environmental pollution resulting from high-carbon fuel consumption at the expense of clean energy use until a threshold growth is attained to reverse this trend. Finally, the study controls for global crisis periods, particularly the 2007/2008 global financial crisis and the 2020 COVID-19 pandemic.

Conceptually, our analysis begins with the baseline model in Eq. (1) that tests the independent linear effect of banking sector development and external debt stock on clean energy consumption, following the approach used in the studies of Diallo and Ouoba (2023), Nyeadi (2023), Appiah et al. (2023), and Chireshe (2021). We then extend the baseline model by introducing the squared term of banking sector development to construct a quadratic specification as shown in Eq. (2). This allows us to follow the EKC framework to investigate the potential curvilinear association between banking sector development and clean energy adoption. Finally, we extend the quadratic model by incorporating an interaction term between bank credit and external credit as in Eq. (3), to assess if their joint role in clean energy consumption is significant and whether these roles are complementary or substitutive. In Eq. (2), we obtain the turning point of the quadratic curve by taking the first derivative with respect to banking sector development and setting it to zero. This turning point, denoted as T, represents the threshold at which the relationship between banking sector development and CE adoption changes direction. Mathematically, the threshold point, T, from Eq. (2), is given as:

$$T = -\frac{\pi_1}{2\pi_2} \tag{4}$$

To examine the moderating role of external debt in the nexus between banking sector development and clean energy consumption, we compute the marginal effect by taking the partial derivative of Eq. (3) with respect to banking sector development as:

$$\frac{\partial CET_{it}}{\partial BSD_{it}} = \lambda_2 + 2\lambda_3 BSD_{it} + \lambda_5 EDS_{it} \quad (5)$$

3.2. Variable specification, measurement, and data sources

The study draws on panel data from 33 SSA countries covering the period 2000 to 2020. Data were obtained from the World Development Indicators (WDI). All variables included in the models, along with their representations and measurements used in this study, are presented in Table 1.

Table 1. Variable specification and measurement

Variable	Label	Measurement/Proxy	Source
Clean Energy Transition	CET	Access to clean fuels and technologies for cooking (% of population)	WDI
Banking Sector Development	BSD	Domestic credit to the private sector by banks (% of GDP).	WDI
Square of Banking Sector Dev.	BSD^2	It is the squared term of banking sector development	Authors
External Debt Stock	EDS	External debt stocks (% of GNI)	WDI
Domestic Investment	INV	Gross fixed capital formation (% of GDP).	WDI
Population	POP	Population growth (annual %)	WDI
Income Level	GDP	GDP per capita (current US$).	WDI
Money Supply	MS	Broad money (% of GDP).	WDI
Carbon Emissions	CO2	CO2 emissions (metric tons per capita).	WDI

3.3. Cross-Sectional Dependence, Panel Unit Root, and Cointegration

Given the geographical proximity and shared economic, political, and cultural characteristics among SSA economies, it is possible that a shock in one economy spreads across other economies in the region. To account for this possibility and avoid spurious estimates, we test for cross-sectional dependence (CD) in the panel data using the Pesaran (2004) CD test, specified as

$$\mathrm{CD} = \sqrt{\left(\frac{2\mathrm{T}}{\mathrm{N}(\mathrm{N}-1)}\right)} \sum_{\mathrm{i}=1}^{\mathrm{n}-1} \sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{N}} (\mathrm{p}_{\mathrm{ij}}) \mathrm{N}(0,1) \quad (6)$$

where N is the number of cross-sectional units (countries), and T is the number of time periods; p_{ij} also represents the pairwise correlation of the residuals between cross-sections i and j. The test statistic is aligned with the standard normal distribution, $N(0,1)$. Additionally, to ensure the stationarity of the panel data and avoid misleading inferences, we apply the Im, Pesaran, and Shin (IPS) panel unit root test. However, given the potential presence of CD in the data, we adopt the Cross-Sectionally Augmented Im, Pesaran, and Shin (CIPS) test developed by Pesaran (2007) to assess unit root properties. This test accounts for cross-sectional dependence and is specified as:

$$\mathrm{CIPS} = \left(\frac{1}{\mathrm{N}}\right) \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{t}_{\mathrm{i}}(\mathrm{N}, \mathrm{T}) \quad (7)$$

Finally, to ascertain whether there is a long-run equilibrium relationship between the variables, we conduct panel cointegration tests using both the Pedroni test (Pedroni, 2001) and the Westerlund test (Westerlund, 2005). However, the Westerlund test is particularly robust to the presence of CD, and it is therefore preferred when such dependence is confirmed in the data.

3.4. Estimation methods

The study employs the Blundell and Bond's (1998) two-step system Generalized Method of Moments (GMM) to deal with potential issues of endogeneity, cross-country heterogeneity, and persistence commonly associated with macro panel data. Additionally, the study's data, comprising more cross-sections (N=33) than time periods (T =21), makes the two-step system GMM superior to other panel estimating methods. However, due to potential cross-sectional dependence in the data, we employ the Driscoll-Kraay Standard

Errors (DKSE) technique for a robustness check, while complementing this approach with the Feasible Generalized Least Squares (FGLS) method. These supplementary methods help to validate the reliability of the system GMM results and ensure robustness with cross-sectional dependence and other panel-specific data challenges.

Due to the strict exogeneity assumption of the error term underlying OLS-based estimation techniques, we estimate static panel specifications with the DKSE and FGLS methods rather than dynamic models. This is because the DKSE and FGLS basically work on OLS principles, and including the lag of the dependent variable as a regressor in the model would violate the exogeneity assumption of OLS, making the DKSE and FGLS estimates of dynamic models inconsistent and biased.

3.5. Model diagnostics tests

The main concern to address with the system GMM estimation method is the potential instrument proliferation that could cause overfitting of the endogenous variables. Consequently, the model must pass both the instrument validity test and the second-order autocorrelation test (Arellano & Bond, 1991). The Hansen test and second-order Arellano and Bond autocorrelation (AR) tests are therefore conducted to confirm the validity of the instruments and the absence of autocorrelation in the residuals, respectively.

4. Results and Discussion

This section contains the empirical results and discussions of the findings. It is organized into three sections. Section 4.1 contains the results of the preliminary tests conducted to ascertain the structure and properties of the dataset for all 33 sampled countries. Section 4.2 presents the regression results to ascertain the relationships between banking sector development, external debt, and clean RE consumption, while Section 4.3 contains the results of the marginal analyses from the two-step system GMM estimations.

Table 2. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Clean Energy (CE)	714	22.50	30.11	0.00	100
Banking Sector Development (BSD)	714	17.20	17.06	0.00	104.85
BSD^2	714	587.5	1382.3	0.00	10993.24
External Debt	693	50.15	38.55	3.89	251.25
Population Growth	714	2.51	0.909	-2.63	5.785
Domestic Investment	714	20.52	8.30	0.00	78.00
GDP per capita	714	2056.9	2876.4	114.4	19141.5
Money Supply	714	29.38	21.64	0.00	156.75
CO2 per capita	714	0.896	1.608	0.022	8.447

Source. Authors. BSD^2 is the square of Banking Sector Development.

The results of the descriptive statistics are reported in Table 2. On average, 22.5% of the population has access to clean fuels and technology for cooking. Private sector credit from banks averages 17.2% of GDP, while external debt stands at an average of 50.15% of gross national income (GNI). Furthermore, the averages of population growth, CO2 per capita, and money supply are 2.51%, 0.896 metric tons, and 29.4% of GDP, respectively. Additionally, domestic investment, measured by gross fixed capital formation, averages 20.5% of GDP, while GDP per capita centers around $2,057.

4.1. Correlation matrix

The correlation coefficient matrix is presented in Table 3. The correlation results indicate that CE adoption is strongly and positively correlated with banking sector development, GDP per capita money supply, and CO2 emissions. In contrast, external

debt and population growth are negatively correlated with clean energy. Additionally, the correlational strength of domestic investment and external debt is weak. Apart from banking sector development and money supply, whose correlations are moderately high, the matrix generally reveals weak correlations among the independent variables.

Table 3. Pairwise Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Clean Energy	1.000								
(2) Banking Sector Dev. (BSD)	0.677	1.000							
(3) BSD²	0.614	0.938	1.000						
(4) External Debt	-0.015	-0.043	0.058	1.000					
(5) Population Growth	-0.582	-0.605	-0.569	0.008	1.000				
(6) Domestic Investment	0.136	0.013	-0.021	-0.165	0.107	1.000			
(7) GDP per capita	0.872	0.552	0.506	-0.113	-0.524	0.209	1.000		
(8) Money Supply	0.748	0.868	0.788	0.025	-0.631	0.072	0.655	1.000	
(9) CO2 per capita	0.785	0.599	0.539	-0.073	-0.491	0.110	0.799	0.585	1.000

Source. Authors. BSD² is the square of Banking Sector Development

4.2. Cross-sectional dependence test

The p-values of the cross-sectional dependence (CD) tests, presented in Table 4, confirm the presence of CD in the data, suggesting possible contagion effects among the SSA economies.

Table 4. Weakly Cross-Sectional Dependence Test

Variable	CD-test	p-value
Clean Energy	42.293	0.000
Banking Sector Development	55.875	0.000
Square of Banking Sector Development	54.676	0.000
External Debt	40.199	0.000
Population Growth	2.843	0.004
Domestic Investment	12.276	0.000
GDP per capita	86.711	0.000
Money Supply	40.332	0.000
CO2 per capita	35.936	0.000

4.3. Unit root test

We present the results of the panel unit root test in Table 5. Due to the confirmed cross-sectional dependence in the data, the CIPS test is considered more robust and reliable than the IPS test. Based on the CIPS results, we establish that banking sector development, external debt, domestic investment, money supply, and CO2 emissions per capita are stationary at level, I(0), while clean energy, population growth, and GDP per capita are stationary at first difference, I(1).

4.5. Cointegration test

Table 6 presents the cointegration test results. Owing to the presence of CD in the data, the Westerlund test, which is more robust to CD, is used to confirm the existence of a long-run relationship among the variables. The Westerlund test confirms cointegration at the 1% level of significance, indicating the existence of a long-run equilibrium relationship among the variables.

Table 5. Unit Root Tests

	IPS		CIPS	
Variables	I(0)	I(1)	I(0)	I(1)
Clean Energy	0.513	-1.783**	-0.795	-2.972***
Banking Sector Development	-1.344**	-3.070***	-2.338***	-4.048***
Square of Banking Sec. Dev.	-1.108	-3.068***	-2.036	-3.780***
External Debt	-1.654	-2.875***	-2.404***	-4.592***
Population Growth	-2.167**	-3.468***	-2.039	-2.689***
Domestic Investment	-2.077***	-3.964***	-2.102*	-4.328***
GDP per capita	-1.962***	-2.915***	-1.954	-3.673***
Money Supply	-1.254	-3.099***	-2.077*	-3.798***
CO2_per capita	-1.778**	-2.587***	-2.151**	-3.818***

Source. Authors. Also, *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Cointegration test

Kao Tests	Statistic	p-value
Modified Dickey-Fuller t	2.8806	0.002
Dickey-Fuller t	3.3036	0.0005
Augmented Dickey-Fuller t	1.874	0.0305
Unadjusted modified Dickey-Fuller t	4.8589	0.0000
Unadjusted Dickey-Fuller t	6.6812	0.0000
Westerlund Test (Variance ratio)	3.0559	0.0011

4.6. Regression results

This section focuses on the main results of the study. It is organized into three sub-sections. The first subsection reports the estimates of the baseline model, which is the linear independent relationship between banking sector development, external debt stock, and clean energy (CE) adoption. The second subsection examines the nonlinear relationship between bank private-sector credit and CE adoption by introducing the square term of bank private-sector credit. The third subsection focuses on the moderating role of external debt in the nexus between banking sector development and CE, and the marginal effect analysis of the interaction term in the quadratic and linear models.

We employ the two-step system GMM as the main estimation technique, and rely on the Driscoll-Kraay Standard Errors and FGLS methods for robustness.

4.6.1. Relationship between banking sector development, external debt, and clean energy

Table 7 presents the empirical results and key findings of the linear, quadratic (curvilinear), and the conditional nexuses between banking sector development, external debt, and CE consumption. Model 1 reports the estimates for the direct linear effects of banking sector development and external debt on clean RE consumption, while Model 2 presents the results for the quadratic (curvilinear) relationship, capturing the modified EKC dynamics between bank private-sector credit and clean energy consumption. Models 3 and 4 present the estimates for the interaction effects, examining how external debt moderates the banking sector development-clean energy relationship in the linear and curvilinear frameworks.

Table 7. Effects of Banking Sector Development and External Debt on Clean Energy Consumption – A Two-Step System GMM Estimates.

Variables	Model 1 Direct Linear Effect	Model 2 Curvilinear Effect	Model 3 Joint Effect (In Quadratic Model)	Model 4 Joint Effect (In Linear Model)
CET_{t-1}	1.0021***	0.9687***	0.9860***	0.9859***
	(0.0139)	(0.0061)	(0.0073)	(0.0045)
Banking Sector Dev.	-0.0787***	-0.0918***	-0.0685***	0.0762**
	(0.0083)	(0.0206)	(0.0225)	(0.0337)
BSD^2		0.0011***	0.0007**	
		(0.0002)	(0.0003)	
External Debt (EDS)	0.0112***	0.0093***	0.0084*	0.0363***
	(0.0035)	(0.0024)	(0.0048)	(0.0066)
BANK*EDS			-0.0007***	-0.0009***
			(0.0002)	(0.0003)
Money supply (MS)	0.0984***	0.0451***	0.0893***	0.0085
	(0.0112)	(0.0071)	(0.0131)	(0.0089)
Population growth	0.4275**	0.0804	0.0443	0.2018
	(0.1979)	(0.1314)	(0.1881)	(0.2488)
CO2 emissions	-0.8128**	-0.3681***	-0.4814**	-0.6598**
	(0.3186)	(0.1353)	(0.1981)	(0.2767)
Domestic investment	-0.0092	0.0531***	0.0407***	0.0135
	(0.0068)	(0.0126)	(0.0106)	(0.0104)
lnGDP	0.8884***	1.1201***	0.2786**	1.2801***
	(0.1567)	(0.0934)	(0.1070)	(0.1845)
2007 Financial Crisis	0.1988***	0.2796***	0.2026***	0.2946***
2008 Financial Crisis	0.3334***	0.1534***	0.1728***	0.3522***
2020 COVID Crisis	-1.0918***	-0.1993***	-0.2384***	-0.1381*
Constant	-7.9661***	-8.4728***	-3.5334***	-10.815***
	(1.2395)	(0.9233)	(1.2280)	(2.1105)
AR (1) test statistic	-1.86	-2.30	-1.84	-1.77
AR (1) p-value	0.062	0.021	0.066	0.077
AR (2) test statistic	0.27	-0.57	-0.04	1.39
AR (2) p-value	0.788	0.571	0.966	0.164
Hansen test statistic	23.63	19.11	20.43	12.85
Hansen p-value	0.130	0.385	0.202	0.684
Diff-in-Hansen p-value	0.543	0.878	0.567	0.661
No. Groups	33	33	33	33
No. Instruments	29	31	30	29
Turning Point (TP)	–	42***	–	–
95% Conf. Interval at TP	–	30.66 – 53.45	–	–

Source. Authors. NB: CET, BSD, EDS, and MS are clean energy consumption, banking sector development, external debt stock, and money supply, respectively, while BSD^2 is the square term of banking sector development and BSD*EDS is an interaction term between banking sector development and external debt stock. The values in parentheses are standard errors. Also, *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Moreover, the reported turning point and confidence interval fall within the min and max range of the banking sector development, which is 0.00 to 104.85 (% of GDP).

4.6.1.1. The linear nexus between bank credit, external debt, and clean energy adoption

Crucially, the model diagnostics in Table 7 show that our models pass the instrument validity test and the second-order Arellano and Bond autocorrelation test reported by the Hansen test/Diff-in-Hansen test and AR (2) test, respectively. Moreover, the relationship between clean energy (CE) transition and its one-year lag is statistically significant, confirming persistence and justifying the study's adoption of the dynamic panel model and the use of the two-step system GMM estimation method.

In Model 1, the estimates show that the banking sector negatively affects clean energy (CE) adoption at the 1% level, indicating that a 1 percentage point increase in bank private-sector credit is associated with a 0.08 percentage point decline in CE consumption, ceteris paribus. The negative relationship is attributed to the low-level financial development in SSA, which prioritizes low-risk, conventional fossil energy investment over novel, high-risk clean energy technology, often lacking proven records of predictable cash flows. Banks in economies with fragile financial systems and weak institutional capacity, including SSA economies, often view clean RE assets as riskier projects, owing to their lack of expertise in evaluating the risk profile of these technologies. Additionally, the huge upfront capital loading in these projects deters banks in the region from investing in novel clean RE projects, shifting investment preference towards proven, low-risk fossil energy assets. The results therefore suggest that SSA may still be in its early stages of economic development, with very limited developed financial sector and institutional framework to drive green policies across sectors. Additionally, energy market distortions could be cited as a contributory factor to this negative relationship between bank private-sector credit and CE adoption. As argued by Cai et al. (2024), governments' subsidies on fossil fuels in SSA economies make fossil energy cheaper, incentivizing its consumption and discouraging investment in clean renewable energy projects.

Furthermore, policy uncertainty surrounding the global energy transition, particularly in SSA, further complicates the financing landscape. The lack of clear, implementable green regulatory frameworks and strategic direction makes renewable energy (RE) projects riskier for risk-averse banks. As Onuoha et al. (2023) explain, the high upfront costs and perceived high risks of RE projects may lead to banks imposing exorbitant interest rates on RE finance, undermining their viability and development in SSA. These findings are consistent with those of Appiah et al. (2023), Onuoha et al. (2023), and Nawaz and Rahman (2023), but inconsistent with the results of Diallo and Ouoba (2023), Nyeadi (2023), and Chireshe (2021). The inconsistencies in the literature underscore the need for further examination into the banking sector development–clean energy adoption nexus.

Moreover, in Model 1, we observe a significant positive relationship between external debt and CE consumption at the 1% level. The two-step system GMM estimates show that a 1 percentage point increase in external debt is associated with a 0.011 percentage point increase in CE consumption, holding other factors constant. This positive relationship is supported by sustainable development theory, which explains that governments may channel external credit into CE projects to achieve energy inclusion and low carbon emissions, enabling them to attain critical environmental, social, and governance (ESG) goals. These findings are consistent with Onuoha et al. (2023), who used the FGLS method on SSA data. However, they contrast with the results of Saleem-Jabari et al. (2022) and Sadiq et al. (2024), who found negative outcomes using data from Turkey and the BRICS countries, respectively. These contrasting outcomes from the SSA and BRICS data could particularly be due to the gap in economic and financial development between these two regions. Contextually, SSA usually relies on external funds to procure capital-intensive projects such as renewable energy, owing to the underdeveloped nature of its financial sector, explaining the positive relationship between external debt and CE consumption.

4.6.1.2. Curvilinear relationship between banking sector development and clean energy

To further understand the relationship between banking sector development and CE adoption in SSA, we estimate a quadratic model (Model 2) between the variables. The results as reported in Table 7, Model 2, indicate a significant U-shaped relationship between bank private-sector credit and CE adoption at the 1% level of significance, implying that banks initially reallocate capital (credits) away from CE but eventually support it beyond a certain threshold. This conclusion is supported by the fact that the second derivative of the quadratic model with respect to banking sector development is positive, and that the estimated turning point falls well within the sample range, which is 0.00 to 104.85 (% of GDP), confirming the U-shaped nature of the curve.

The U-shaped curve implies that in the early stages of financial development, banks in SSA tend to favor brown lending (e.g., fossil energy investment), which is perceived as more stable and profitable due to its proven nature and relatively low risk profile. At this stage, environmental concerns are often given less priority, consistent with the EKC hypothesis. However, as economies grow and become more environmentally conscious, they begin to implement green policies and regulatory frameworks that promote sustainability. This paradigm shift increases the demand for clean energy and encourages banks to align their investment strategies with the green trends, promoting bank capital flow to renewable assets. Furthermore, at advanced stages of economic and financial development, traditional sectors become saturated with bank investment, compelling banks to search for unconventional investment prospects. Thus, clean renewable investment becomes a more attractive alternative to competing banks at the advanced stages of development. At this stage, banks would also have acquired the requisite institutional capacity to evaluate CE projects, promoting green lending. Consequently, the relationship between banking sector development and clean energy adoption changes from negative to positive.

We compute the turning point of the U-shaped curve at approximately 42% of GDP, indicating that the banking sector must reach this level of development before it will begin to influence the clean energy transition positively. Considering that bank private-sector credit averages at 17% of GDP (see Descriptive Statistics in Table 2), it could therefore take a considerable amount of time for economies in SSA to reach the 42% (of GDP) threshold. The findings suggest that clean energy transition through the banking sector in SSA is a long-term process. Based on the estimated data, only Mauritius, Cape Verde, and South Africa, out of the 33 countries, lie above the 42% threshold.

4.6.1.3. Moderating role of external debt in the banking sector development-clean energy nexus

In Models 3 and 4, we explore the complex dynamics of the banking sector development and CE consumption link, moderated by external debt within the quadratic and linear frameworks. The results as reported in Table 7 indicate that the interaction term between banking sector development and external debt stock is significantly negative. However, the interpretation of the coefficient of the interaction term requires computing the marginal effects.

4.6.1.4. Effects of banking sector development on CE adoption moderated by external debt

The results of the marginal analysis, showing how private-sector bank credit connects to clean energy consumption at different levels of external debt and bank credit itself, are presented in Table 8. The analyses show that too much private-sector bank credit (i.e., too much financialization) combined with too much external debt reduces the marginal benefit of banking sector development towards the clean energy transition. These results suggest that greater bank financial deepening, together with the structural drag of high external debt ratios on the financial market, heightens risk aversion and, consequently, causes distortions in bank credit allocation, as the debt overhang theory and Minsky (1974)'s financial market distortion theory explain. Therefore, too much bank

credit coupled with debt overhang turns the banking sector into a channel of structural distortion rather than a supportive mechanism for clean energy transition. The trend is consistent with the marginal effect analysis of the linear interaction model (Model 4), which also indicates that low debt levels (up to the 50th percentile value) support bank credit to the private sector in fostering clean energy adoption, but high-debt levels (beyond the 50th percentile value) do not.

Table 8. Marginal Effect of Banking Sector Development on Clean Energy Transition at Different Levels of both External Debt and Bank Credit. (A Two-Step System GMM Estimates)

Percentiles	Percentile Values (External Debt)	Percentile Values (Bank Sector Dev.)	Coefficients (Quadratic Model) Increasing EDS & BSD	Coefficients (Linear Model) Increasing EDS only
25%	23.28	7.89	-0.0728	0.0542*
50%	38.91	12.36	-0.0769	0.0395*
75%	65.14	20.13	-0.0834	0.0148
90%	96.16	33.11	-0.0855	-0.0145

Source. Authors. EDS and BSD are external debt stock and banking sector development, respectively. Note: * represents statistical significance at the 10% level.

For comparative robustness of the system GMM estimates, we also present static Driscoll-Kraay Standard Errors (DKSE) and FGLS estimates to control for cross-sectional dependence (CD). The DKSE and FGLS results of our baseline model and the nonlinear analysis are consistent with those of our main technique, the two-step system GMM. The DKSE and FGLS methods consistently corroborate the GMM's estimate of the negative association between bank private-sector credit and clean energy consumption, as well as the positive effect of external debt on clean energy use. Moreover, the DKSE and FGLS techniques confirm the U-shaped association between bank private-sector credit and clean energy consumption, with the turning points estimated at 43% (of GDP) in each case. This is practically consistent with the system GMM's estimate of a 42% threshold, indicating very robust estimates and stable model specifications (see Tables A & B in the Appendix).

However, while the static DKSE and FGLS marginal analyses show a negative moderating effect of the combined bank credit and external debt in the nexus being examined, similar to our system GMM estimates, the results point to an easing negative marginal effect with increasing bank credit and external debt expansions. Additionally, not all of the constituent coefficients in the marginal effect computations with DKSE and FGLS techniques are significant, potentially affecting the statistical precision of their marginal analysis estimates. We attribute the inconsistencies in the marginal effect steepness between the estimation approaches to the inadequacies of the static OLS-based DKSE and FGLS techniques to deal with the unobserved individual country heterogeneity and to address endogeneity and persistence over many time periods. Since OLS-based estimators don't difference the data, these structural deficits could be absorbed into the more complex and nuanced marginal estimates, explaining the attenuation in the static DKSE and FGLS marginal effect estimation. This reinforces our selection of the dynamic system GMM technique ahead of the DKSE and FGLS despite the cross-sectional dependence. These findings represent major contributions to the literature on the finance–clean energy nexus in developing economies, and could provide the framework for clean energy transition policy in the region.

The control variables used in the models also exhibit significant effects on clean energy adoption. Particularly, GDP per capita, money supply, and population growth have positive associations with clean energy consumption, while CO2 emissions show a negative connection with the dependent variable. The GDP's positive relationship with clean energy consumption is linked to high-income economies' stronger environmental and regulatory oversight, prioritizing sustainable and inclusive development over raw quantitative growth. This incentivizes the consumption of clean energy over fossil energy

as economies become wealthier, in line with the EKC theory. Moreover, the positive connection between money supply and clean energy use is attributed to the reduced cost of capital and increased credit expansion associated with increased broad money supply, making it relatively easier for clean energy projects to obtain funding. This reasoning is founded on the credit channel theory, which explains the mechanism of credit transmission.

In addition, population growth causes a surge in total energy demand, putting pressure on existing grids and compelling modern governments to accelerate the scaling up of clean energy alternatives through policy responses that are consistent with global sustainable development goals. Moreover, increased CO2 emissions having a negative connection with the clean energy transition suggests that SSA economies are still at their initial stages of growth, where rising industrialization increases the demand for fossil energy at the expense of renewable alternatives. This is consistent with the predictions of the EKC model, which explains that there is low priority for environmental sustainability at the initial stages of growth.

Finally, the study's control of global crisis periods in the models produces contrasting outcomes. While the 2007/2008 global financial crisis shows a positive association with clean energy adoption, the 2020 global COVID pandemic is negatively linked to the dependent variable. These contrasting effects of the global crises on clean energy may be attributed to the different nature of the shocks. Whereas the financial crisis was a demand-side shock, inducing stimulus injections during the crisis period and potentially exerting a positive externality on clean energy, the COVID-19 crisis was both a demand-side and supply-side global shock, causing a general economic freeze across the world and a decline in the demand and supply of clean energy.

5. Conclusion and recommendations

5.1. Conclusion

As global attention intensifies around climate change and environmental degradation, sustainable development has emerged as a central policy objective. A key component of this agenda is the transition from fossil-based energy systems to renewable alternatives. The literature consistently links greenhouse gas emissions to rising global temperatures and climate variability. In response to these challenges, the United Nations, through Sustainable Development Goal 7, is leading a global campaign to speed up the transition to clean renewable energy usage.

In alignment with the new paradigm, this study examines the roles of banking sector development and external debt in driving the energy transition across 33 countries in SSA over the period 2000 to 2020. Preliminary diagnostics confirm instrument validity, persistence, cross-sectional dependence, a mix of I(0) and I(1) stationarity levels, and cointegration among variables. To address these panel data characteristics, the study employs the two-step system GMM as its primary estimation technique, while relying on Driscoll-Kraay Standard Errors and Feasible Generalized Least Squares estimation techniques for robustness.

The study, in its baseline linear analysis, finds that bank private-sector credit negatively affects clean energy consumption, whereas external debt shows a positive association with clean energy. However, further analyses establish a U-shaped association between banking sector development and clean energy (CE) adoption at the 1% level of significance. This implies that banking sector development initially inhibits CE adoption but begins to support it once a critical threshold, estimated at 42% of GDP, is reached. This observation aligns with the EKC hypothesis. Additionally, while external debt unconditionally supports CE consumption, it negatively moderates the banking sector development-clean energy nexus when external debt expansions are simultaneously combined with increased bank private-sector credit. This could likely be due to

heightened debt overhang risk and financial market distortions, consequently increasing banks' risk aversion towards capital-intensive renewable energy projects.

Among the control variables, GDP per capita, money supply, and population growth have positive associations with clean energy consumption, while CO2 emissions show a negative connection with the dependent variable. Moreover, the 2007/2008 global financial crisis positively affects the clean energy transition, whereas the 2020 COVID period negatively affects the transition to clean energy in SSA.

Based on these findings, we conclude that while both bank private-sector credit and external credit are critical to fostering the clean energy transition, the former promotes the transition to clean energy only after reaching a critical threshold of 42% of GDP, whereas the latter only supports the cause when used independently. Additionally, combining too much external debt with too much private-sector bank credit reduces the marginal benefits of banking sector development to the renewable energy transition. The results suggest that the roles of banking sector development and external debt in the SSA's energy transition agenda are more independent and substitutive rather than complementary.

5.2. Policy recommendations

We recommend that governments and central banks of SSA countries accelerate the development of the banking sector and align financial systems with sustainability goals to enable banks to reach the 42% (of GDP) required threshold faster, so they can support the clean energy transition cause. Alternatively, we recommend prudent and sustainable debt management to allow governments in the region the needed fiscal space to attract concessional external capital to support clean energy projects. Finally, we propose a debt-for-climate swap policy to SSA's development partners, including the World Bank and the African Development Bank, such that governments in the region may be compelled to reinvest forgiven debts into clean energy projects to enhance the region's push for sustainable/inclusive development, at the core of which is the clean energy transition.

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Appendix

Table A. Effects of Banking Sector Development and External Debt on Clean Energy Consumption – A Driscoll-Kraay Standard Errors Estimates (Robustness Check)

Variables	Model 1 Direct Linear Effect	Model 2 Curvilinear Effect	Model 3 Joint Effect (In Quadratic Model)	Model 4 Joint Effect (In Linear Model)
Banking Sec. Dev. (BSD)	-0.0078	-0.1947*	-0.2840**	-0.3041**
	(0.0868)	(0.1059)	(0.1289)	(0.1129)
BSD^2		0.0023***	0.00041	
		(0.0006)	(0.0010)	
External Debt (EDS)	0.0889***	0.0805***	0.0358**	0.0367**
	(0.0226)	(0.0210)	(0.0149)	(0.0154)
BSD*EDS			0.0045***	0.0043***
			(0.0012)	(0.0009)
Money supply (MS)	0.3526***	0.3671***	0.3234***	0.3272***
	(0.0921)	(0.0941)	(0.1090)	(0.1079)
Population growth	0.9252*	1.0699*	0.6617	0.6981
	(0.4648)	(0.5176)	(0.4619)	(0.4691)
CO2 emissions	3.7891***	3.7569***	4.9581***	4.1096***
	(0.5269)	(0.5371)	(0.4642)	(0.5142)
Domestic investment	-0.2962***	-0.2994***	-0.3019***	-0.3022***
	(0.0897)	(0.0864)	(0.0913)	(0.0903)
lnGDP per capita	17.3491***	17.4596***	16.8548***	16.8954***
	(1.6458)	(1.7060)	(0.5793)	(1.5901)
2007 Financial Crisis	-0.3822	-0.6321	-0.3793	-0.4224
2008 Financial Crisis	-2.1906*	-2.4970**	-2.0569*	-2.1155*
2020 COVID Crisis	-2.0116	-1.8799	-2.6499*	-2.5995*
Constant	-113.0334***	-112.185***	-104.9905***	-105.1954***
	(11.1677)	(11.3208)	(9.5076)	(9.7317)
No. of Observation	693	693	693	693
No. of Groups	33	33	33	33
F-statistics	7887***	2499***	2603***	4677***
Adjusted R^2	84.08%	84.22%	84.70%	84.70%
Turning point (TP)	–	43**	–	–
95% Conf. Interval at TP	–	5.99 – 80.30	–	–
Marginal Effect Analysis:				
25th percentile value	–	–	EDS=23.28, BSD=7.89	
Calculated Coefficient			-0.1856	
50th percentile value	–	–	EDS=38.91, BSD=12.36	
Calculated Coefficient			-0.1190	
75th percentile value	–	–	EDS=65.14, BSD=2013	
Calculated Coefficient			-0.0072	

Source. Authors. NB: BSD and EDS are banking sector development and external debt stock, respectively, while BSD^2 is the square term of banking sector development and BANK*EDS is an interaction term between banking sector development and external debt stock. The values in parentheses are standard errors. Also, *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Moreover, the reported turning point of 43% falls well within the sample range, which is 0.00 to 104.85 (% of GDP).

Table B. Effects of Banking Sector Development and External Debt on Clean Energy Consumption – A Feasible Generalized Least Squares Estimates (Robustness Check)

Variables	Model 1 Direct Linear Effect	Model 2 Curvilinear Effect	Model 3 Joint Effect (In Quadratic Model)	Model 4 Joint Effect (In Linear Model)
Banking Sec Dev. (BSD)	-0.0078	-0.1947*	-0.2840***	-0.3041**
	(0.0713)	(0.1040)	(0.1042)	(0.0897)
BSD^2		0.0023**	0.00041	
		(0.0009)	(0.0011)	
External Debt (EDS)	0.0889***	0.0805***	0.0358**	0.0367**
	(0.0116)	(0.0120)	(0.0152)	(0.0151)
BSD*EDS			0.0045***	0.0043***
			(0.0010)	(0.0008)
Money supply (MS)	0.3526***	0.3671***	0.3234***	0.3272***
	(0.0558)	(0.0559)	(0.0558)	(0.0549)
Population growth	0.9252	1.0699*	0.6617	0.6981
	(0.6720)	(0.6717)	(0.6672)	(0.6603)
CO2 emissions	3.7891***	3.7569***	4.9581***	4.9016***
	(0.4391)	(0.4374)	(0.5021)	(0.4795)
Domestic investment	-0.2962***	-0.2994***	-0.3019***	-0.3022***
	(0.0563)	(0.0560)	(0.0552)	(0.0552)
lnGDP per capita	17.3491***	17.4596***	16.8548***	16.8954***
	(0.6897)	(0.6881)	(0.690)	(1.6817)
2007 Financial Crisis	-0.3822	-0.6321	-0.3793	-0.4224
2008 Financial Crisis	-2.1906	-2.4970**	-2.0569*	-2.1155*
2020 COVID Crisis	-2.0116	-1.8799	-2.6499*	-2.5995*
Constant	-113.0334***	-112.185***	-104.9905***	-105.1954***
	(5.1224)	(5.1118)	(5.2657)	(5.2385)
No. of Observations	693	693	693	693
No. of Groups	33	33	33	33
Wald χ^2	3661***	3699***	3836***	–
Turning point (TP)	–	43**	–	–
Marginal Effect Analysis:				
25th percentile value	–	–	EDS=23.28, BSD=7.89	
Calculated Coefficient			-0.1856	
50th percentile value	–	–	EDS=38.91, BSD=12.36	
Calculated Coefficient			-0.1190	
75th percentile value	–	–	EDS=65.14, BSD=2013	
Calculated Coefficient			-0.0072	

Source. Authors. NB: BSD and EDS are banking sector development and external debt stock, respectively, while BSD^2 is the square term of banking sector development and BANK*EDS is an interaction term between banking sector development and external debt stock. The values in parentheses are standard errors. Also, *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Moreover, the reported turning point of 43% falls well within the sample range, which is 0.00 to 104.85 (% of GDP).

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