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FINANCE, GOVERNANCE, AND RENEWABLE ENERGY TRANSITIONS IN SUB-SAHARAN AFRICA: TESTING THE ENERGY KUZNETS CURVE

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Abstract

Purpose: This study explores how the interplay between financial sector development (FSD) and governance quality (GOVE) influences the adoption of modern renewable energy (MREN) in 11 sub-Saharan African (SSA) countries (1999–2023). It also tests the modern renewable energy-environmental Kuznets curve (MRENEKC) hypothesis, assessing the contribution of inclusive growth, urbanization, and trade openness in shaping the regions renewable energy transitions.
Research methodology: Employing a pooled mean group autoregressive distributed lag model, this study captures both short- and long-term dynamics, while accounting for cross-sectional dependence and regional heterogeneity. By focusing on the interactive roles of FSD and GOVE, the study contributes to the literature on sustainable energy development in emerging economies.
Results: The results confirm the validity of the MRENEKC hypothesis, revealing a U-shaped relationship between income and MREN adoption. FSD and GOVE, significantly drive MREN adoption, though effects vary regionally. East/Southern Africa leveraged FSD effectively for geothermal and wind projects (Kenya, Tanzania), whereas West/Central Africa's lax governance structure diminishes FSD's influence. These results reveal the need for regionally tailored institutional and policy reforms that integrate financial infrastructure with institutional quality to accelerate renewable energy transitions.
Novelty: This study uniquely applies the Modern Renewable Energy-Environmental Kuznets Curve (MRENEKC) framework within the SSA context to offer a comprehensive analysis that links FSD and GOVE to MREN adoption. It fills a critical gap by assessing this underexplored dynamic, and provides actionable insights for policy targeting green growth, energy access, and institutional reform in SSA.

Keywords: Financial sector development, Modern Renewable Energy, Governance Quality, Sub-Saharan Africa, Modern Renewable Energy Kuznets Curve

JEL cassificatrion: F64, G28, O13, Q28, Q43

Introduction

The increasing influence of renewable energy (REN) on environmental sustainability has been widely recognized. However, the sluggish global transition to modern renewable energy (MREN) sources such as hydropower, solar, and wind energy remains a pressing challenge, particularly in Sub-Saharan Africa (SSA). The region's slow adoption of MREN poses a significant threat to meeting global sustainability targets, especially the Sustainable Development Goal (SDG) 7, focusing on access to affordable, reliable, and MREN.

Despite global initiatives to increase MREN consumption and improve environmental quality, the region's sustained reliance on fossil fuels continues to hinder progress towards carbon neutrality and ecological sustainability (Udoh et al., 2024). As such, the annual growth of MREN consumption in SSA is only 1%, far below the global rate of 10.9% in 2022, a drop from the 13.4% average between 2011 and 2022 (BP Statistical Review of World Energy, 2022; IEA, 2022). This stagnation threatens SSA's ability to meet its environmental commitments, including the 2015 Paris Agreement and the 2005 Kyoto Protocol (Kyriakopoulos et al., 2023).

The region's slow MREN adoption can be attributed to several region-specific factors, including adverse climate conditions, aging hydropower infrastructure, and limited financial access to large-scale renewable projects such as solar and wind energy installations (Lake Turkana in Kenya). These factors, coupled with SSA's rapid urbanization, population growth, and substantial foreign direct investment (FDI) in carbon-intensive sectors, further complicate the region's energy transition.

The realization of the UN carbon neutrality target by 2050 through global initiatives such as the United Nations' Sustainable Energy for All (2012), which requires MREN to account for 79% of global energy consumption (Tan, Uprasen, 2022) appears challenging for SSA because of the region's socio-economic constraints, including underdeveloped financial markets, weak governance structures, and limited openness to green energy trade and technology. The contribution of MREN in enhancing ecological quality, and energy security, and sustainable development has been acknowledged in the extant literature (Prempeh, 2024; Udo et al., 2024; Udoh et al., 2024; Inim et al., 2024).

The role of financial sector development (FSD) in supporting MREN investments has been widely documented (Ndubuaku et al., 2021; Samuel et al., 2019). An efficient financial system provides market liquidity, risk management, and price discovery, which are crucial for enhancing investment in sustainable energy projects (Samuel et al., 2019; Udo et al., 2024). However, SSA's and financial infrastructure remain underdeveloped and characterized by inadequate capital markets, political instability, and weak regulatory frameworks, limiting their capacity to support MREN projects (Samuel et al., 2023; Samuel et al., 2019).

Government quality (GOVE) also plays a pivotal role in shaping MREN adoption. Studies have revealed that countries with robust governance frameworks attract and sustain REN investment (Akpanke et al., 2023). However, the governance-finance nexus remains underexplored in SSA, particularly concerning how governance reforms can foster the growth of regional REN sectors.

Empirical evidence on the FSD-MREN relationship remains mixed. While some studies highlight the positive role of FSD in promoting MREN through enhanced financial intermediation (Anton, Nucu, 2020), others suggest that FSD often favours non-renewable energy projects because of the perceived risks associated with green investments (Samuel et al., 2023; Akpanke et al., 2023). Most existing studies focus on regions such as Latin America, the Caribbean, the

European Union (Pablo-Romero, De Jesus, 2016), EU27 countries (Pablo-Romero et al., 2017), Chinese Provinces (Shahbaz et al., 2020), and Egypt (Mahmood et al., 2021) overlooking SSA's unique energy challenges and environmental vulnerabilities. Additionally, previous studies predominantly aggregated MREN without considering the distinct characteristics of different energy sources.

Given this diversity of results, this study addresses this gap by applying the Modern Renewable Energy-Environmental Kuznets Curve (MRENEKC) framework to explore the dynamics of FSD and MREN in SSA. The MRENEKC hypothesis posits that economies initially prioritize non-renewable energy (NREN) to support industrialization. However, as income levels rise and environmental awareness grows, economies are in transition toward greater MREN consumption, thereby improving environmental quality (Yao et al., 2019). This study disaggregates MREN into solar, wind, hydro, and geothermal sources to provide a nuanced understanding of SSA's energy transition. Despite the region's vast potential – 350 GW of hydro, 110 GW of wind, and 15 GW of geothermal energy–each energy source faces specific challenges; for example, hydropower is heavily influenced by climate variability, whereas solar deployment in countries such as Kenya, South Africa, and Nigeria is affected by the high cost of solar panels. Wind power potential is strong in Kenya, South Africa, and Tanzania, and geothermal energy is predominantly used in Kenya and Ethiopia, with Kenya leading SSA's geothermal production of SSA because of its location along the East African Rift.

This study also evaluated the interactive roles of GOVE, trade openness (TOPE), and urbanization (URB) in shaping MREN outcomes. Using data from 11 SSA countries (1999–2023), this study employs the panel ARDL-PMG model to capture both short- and long-term dynamics, accounting for heterogeneity and cross-sectional dependence. The key contributions of this study are as follows:

1. Application of the MRENEKC framework in SSA to assess the role of FSD and socioeconomic variables in the region's energy transition.
2. Empirical validation of the MRENEKC hypothesis in SSA offers new insights into a region's path toward sustainable development.
3. Evaluation of the roles of GOVE, TOPE, and URB in shaping MREN consumption and providing critical policy insights to foster green energy transitions.
4. The disaggregation of MREN sources offers region-specific insights into SSA's REN landscape of SSA, addressing the distinct challenges and opportunities for solar, wind, hydro, and geothermal energy.

The findings reveal that, while FSD generally supports MREN consumption in SSA, its effectiveness is moderated by GOVE and regional economic conditions. FSD's positive effects of FSD are more significant in West and Central Africa, whereas East Africa faces short-term challenges owing to insufficient financial instruments and supportive regulations. The results confirm the MRENEKC framework, underscoring the importance of aligning financial systems and governance structures with the MREN objectives. Additionally, TOPE and GOVE reforms are critical for fostering long-term MREN development, whereas the influence of urbanization on MREN depends on regional infrastructure and energy policies. The remainder of this paper is organized as follows. Section 2 reviews the literature, section 3 presents the methodology, section 4 discusses the findings, and section 5 presents the conclusions and policy recommendations.

1. Review of literature

1.1. Modern Renewable Energy and the Environmental Kuznets Curve (MRENEKC)

The MRENEKC model, an extension of the classical environmental Kuznets curve (EKC) framework by Grossman and Krueger (1991), explores the dynamic nexus between EGR and environmental degradation by incorporating modern renewable energy (MREN) technologies. The EKC hypothesizes an inverted U-shaped nexus between economic growth (EGR) and environmental degradation where initial stages of industrialization degrade environmental quality due to increased dependency on fossil fuels for industrialization, but as the economy evolves with increase in income level and technology advancement, environmental quality is improved through the adoption of MREN.

MREN adoption plays a pivotal role as a crucial mechanism for decoupling EGR from environmental degradation, particularly in post-crisis contexts. Tamazian and Rao (2010); Udo et al. (2025); Emmanuel et al. (2023) revealed that institutional quality and FSD are key drivers of cleaner energy transitions. While Africa contributes only around 4% of global greenhouse gas emissions, it is highly vulnerable to climate change (Udo et al., 2024). The MRENEKC hypothesis provides a valuable framework for understanding how increase in income levels, financial capacity, and governance reforms intermingle with drives of MREN adoption. Boluk and Mert (2014), Inim et, al. (2024), Enemuo et al (2025) and Yao et al. (2019) in confirming a U-shaped nexus between EGR and MREN, argued that the reliance on fossil fuel for initial growth and development degrades environmental quality, but as the economy evolves the transition to renewable alternatives through the increase in incomes and infrastructure improves environmental quality. Despite technological advancements and international climate agreements such as the Paris Agreement empirical validation of the MRENEKC model in SSA remains limited, and uncertain whether SSA's trajectory will align with the traditional EKC. This study hypothesized that:

H_0: There is a U-shaped nexus between economic growth and modern renewable energy consumption in SSA, where environmental degradation initially worsens but improves as income levels and institutional capacity rise.

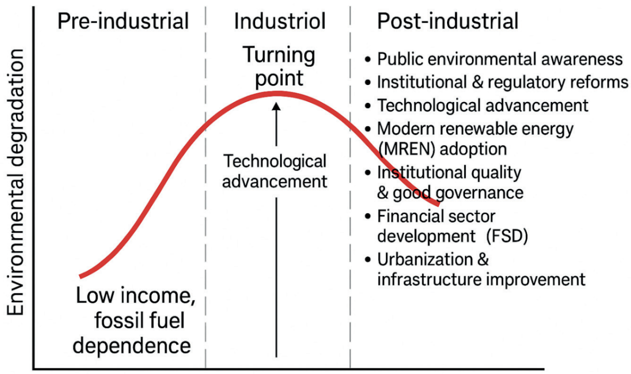

Figure 1. Environmental Kuznets Curve

Source: author's (2024).

1.2. FSD-MREN nexus

FSD plays a critical role in enhancing the efficiency of the banking systems, capital markets, and financial institutions to support the adoption of MREN through improved access to capital and reduction in borrow costs (Samuel et al., 2019; Qamruzzaman, Jianguo, 2020). However, while the FSD-MREN nexus has been widely assessed in developed regions (China, EU), it remains underexplored in SSA due to the underdevelopment of the capital markets and limited financial inclusion decreasing access to substantial investment capital. Large-scale MREN projects require substantial upfront investment. However, high interest rates, short loan durations, and a lack of tailored green financial products limit access to funding, particularly in rural SSA. These structural barriers make microcredit and pay-as-you-go financing difficult to scale.

Robust FSD is critical in bridging the financing gap for MREN adoption in SSA. As such Zhang et al. (2021), Samuel et al. (2023) and Udo et al. (2025) revealed the potential of green financial products and digital financial services to unlock new financing channels. Therefore, improving the FSD is critical for SSA's transition of SSA to cleaner energy systems. This study hypothesized that:

H_0: FSD significantly influences the adoption of MREN across SSA.

1.3. EGR and MREN consumption

The nexus between economic growth (EGR) and MREN is multifaceted, particularly in regions such as SSA where energy demand is an outpacing supply. Extant studies revealed that economic expansion increases reliance on MREN (Can, Korkmaz, 2020; Güney, 2021). However, other studies argue that in the early stages of industrialization, energy demand dependent on fossil fuels exacerbates environmental degradation (Dogan et al., 2020; Inim et al., 2024). However, as the economy evolves with income growth, environmental sustainability is prioritized, thus supporting the MREN adoption which aligns with the MRENEKC framework (Nabaweesi et al., 2023; Samuel et al., 2021). Evidence from Kenya and Ethiopia reveals that geothermal and hydropower investments drives their shift toward renewables (IRENA, 2022; Güney et al., 2022). However, the broader interaction between EGR-MREN in SSA remains empirically understudied. This research contributes to filling that gap by analysing both short- and long-term effects of EGR on MREN in SSA.

1.4. TOPE-MREN

Trade openness (TOPE) globally is acknowledged as a facilitator of clean energy transitions (Alam, Murad, 2020), innovation, and best practices. In the OECD and South Asia, increased TOPE positively influenced MREN adoption through access to advanced technologies and financial resources necessary for clean energy transitions (Alam, Murad, 2020). However, SSA's dependence on fossil fuel imports continues to hinder progress to environmental quality (Dingru et al., 2023; Udo et al., 2025). Results from Dingru et al. (2023); Samuel et al. (2023), Udoh et al (2024), Emmanuel et al. (2023), Prince et al. (2021) and Uzar (2020) report a mixed effect of TOPE on MREN in the region, due to structural dependencies and lax domestic markets for renewable technologies. Nevertheless, initiatives like the African Continental Free Trade Area (AfCFTA) offer opportunities to shift this trajectory by enhancing regional collaboration in clean technology transfer and infrastructure investment. This study investigates how trade dynamics and agreements such as AfCFTA influence MREN adoption in SSA.

1.5. GOVE-MREN nexus

Governance quality (GOVE) is fundamental to fostering an enabling environment for MREN through transparent regulations, anti-corruption measures, and institutional accountability (Huang et al., 2022). A robust GOVE system, characterized by transparency, accountability, and regulatory enforcement in regions such as the MENA and Southeast Asia, have successfully fostered MREN adoption through carbon pricing, REN subsidies, and institutional reforms that encourages private sector investment in REN projects (Huang et al., 2022; Prince et al., 2021). However, in SSA, the influence of GOVE on the MREN remains ambiguous. Dossou et al. (2020) reported a positive correlation between GOVE and REN, other studies have reported a negative nexus due to corruption and institutional inefficiencies (Asongu, Odhiambo, 2021; Emmanuel et al., 2023; Inim et al., 2024). Additionally, limited financial resources and technical expertise exacerbate governance challenges. This study explores the short- and long-term influence of GOVE on MREN, with a focus on institutional reforms and public policy. This study hypothesized that

H_0: GOVE significantly influences the adoption of MREN in SSA, with varying short- and long-term effects across regions.

1.6. Urbanization (URB) and Renewable Energy (REN) consumption

In developed economies URB significantly influences energy demand and consumption patterns, by facilitating MREN adoption through smart cities and modern infrastructure. In developing economies particularly, SSA URB often outpaces infrastructure development and increased reliance on traditional fuels (Yin, Qamruzzaman, 2024; Udo et al., 2024). Despite these challenges in SSA, urban areas offer potential entry points for MREN, especially through decentralized systems and solar technologies. This study evaluates how urban growth in SSA influences MREN, identifying both barriers and enabling factors.

1.7. Integrated analysis of MRENEKC in SSA

This study extends the MRENEKC framework by comprehensive analysing and integrating the interactions between FSD, GOVE, EGR, TOPE, and URB on MREN adoption in SSA. While the MRENEKC nonlinear nexus between EGR and MREN is moderated by governance, financial depth, trade policies, and urban development. Fragmented institutions, limited access to green finance, and infrastructural and institutional deficits hamper the transition despite regional efforts like AfCFTA. By capturing cross-sectional and regional heterogeneities, this study offers a holistic understanding of the policy and economic conditions necessary for sustainable energy transitions. It fills a crucial empirical gap by focusing on modern renewables (excluding traditional biomass), region-specific challenges, and institutional effectiveness in SSA.

2. Methodology

2.1. Theoretical framework

This study adopted the MRENEKC framework rooted in the EKC hypothesis to examine the nexus between FSD, EGR, and MREN consumption in SSA. The framework is based on the study by Yao et al. (2019) and expanded by Nabaweesi et al. (2023), emphasizing the nonlinear nexus between EGR and environmental quality, represented by MREN. The EKC model is expressed as follows:

$$\text{ENQ} = f(\text{EGR}, \text{EGR}^2, \text{Z}) \tag{1}$$

where: ENQ – environmental quality proxied by (MREN), EGR – inclusive growth, EGR^2 – test for a U-shaped relationship, and Z – other variables (FSD, TOPE, GOVE, and URB).

Expanding the EKC model to incorporate the MRENEKC framework:
The expanded EKC model to incorporate variables such as TOPE, GOVE, and URB is expressed as:

$$\text{MRENECK} = f(\text{EGR}, \text{EGR}^2, \text{FSD}, \text{TOPE}, \text{GOVE}, \text{URB}) \tag{2}$$

To mitigate heteroscedasticity, the model was transformed into a panel-log format:

$$\begin{aligned}\text{InMRENECK}_{it} = \beta_{it} + \beta_1\text{InEGR}_{it} + \beta_2\text{InEGR}^2{}_{it} + \beta_3\text{InFSD}_{it} + \beta_4\text{InTOPE}_{it} + \\ + \beta_5\text{InGOVE}_{it} + \beta_6\text{InURB}_{it} + \varepsilon_{it}\end{aligned} \tag{3}$$

where: β_{it} – intercept, β_1–β_6 – slope coefficients measuring elasticities, *i* – SSA country, *t* – time series (1999–2023), ε_{it} – error term.

The MRENEKC hypothesis was confirmed if $\beta_1 < 0$ and $\beta_1 > 0$, indicating a transition from negative (EGR) to positive (EGR^2), thus confirming a U-shaped link between EGR and MREN consumption. Table 1 lists the variables, their descriptions, and their sources.

Table 1. Variables of the Study

Variables	Description	Data Source
MREN – (Modern renewable energy	Total final energy consumption excluding the traditional biomass (solar, hydro, wind, geothermal)	World Development Indicators (WDI) (2023)
Urbanization (URB)	Percent of total population living in urban areas.	
Trade openness (TOPE)	The sum of exports and imports as percent of GDP.	
EGR (Inclusive growth)	GDP per capita in current US$	
EGR^2 (Square of Inclusive growth)	Tests for the U-shaped MRENEKC hypothesis	Calculated from EGR
FSD (Financial development)	The financial development index includes measures of financial size, depth, and openness such as M2/GDP, stock market capitalization, private sector credit, and net FDI inflows	World Bank's Global Financial Development Database (2023)
Governance Quality (GOVE)	Composite index created using PCA, covering government effectiveness, regulatory quality, control of corruption, political stability, and rule of law	World Governance Indicators (WGI) (2023)

Source: authors (2024).

2.2. Regional representation

To capture regional diversity and ensure robustness, this study covers 11 SSA countries selected for their diversity in the FSD and REN initiatives. Table 2 provides the regional grouping and the rationale for selecting these countries.

Table 2. Regional representation

Region	Countries	Justifications
West Africa	Nigeria, Ghana, Côte d'Ivoire	Robust FSD growth and REN adoption, particularly in solar and hydropower
East Africa	Kenya, Ethiopia, Tanzania, Uganda	Leaders in financial inclusion and REN, with notable geothermal, wind, and hydropower projects
Southern Africa	South Africa, Namibia, Botswana	Advanced financial markets and environmental challenges in South Africa; emerging REN initiatives in Namibia and Botswana
Central Africa	Cameroon	Significant financial reforms and REN investments

Source: authors (2024).

2.3. Estimation strategy

This study employs a dynamic panel ARDL model to assess the long-short links between FSD, MREN, and other variables. The ARDL-Pooled Mean Group (PMG) approach accounts for cross-country heterogeneity in short-term dynamics while assuming homogeneity in a long-run link. The versatility of the model in handling variables with mixed integration orders (I(0) and I(1)) makes it suitable for this study. Additionally, its lag structure mitigates endogeneity concerns and enhances the robustness of estimations by controlling for omitted variable bias and serial correlation. The Hausman test supports the PMG estimator over the Mean Group (MG) and Dynamic Fixed Effect (DFE) models. Pesaran's (2004) CSD test was adopted to address CSD. Second-generation unit root tests models of the Cross-sectional augmented Dickey-Fuller (CADF) and Cross-Sectional Augmented Im, Pesaran, and Shin (CIPS) tests confirm stationarity. Pedroni and Kao's cointegration tests were used to assess the long-term relationships among the variables. The final equation estimates both short- and long-term dynamics while considering cross-country heterogeneity in SSA. The ARDL-PMG model is expressed as follows:

$$\begin{aligned}\Delta \text{InMREN}_{it} &= \varphi_{it} + \phi_1 \text{InMREN}_{i,t-1} + a_1 \text{InEGR}_{it} + a_2 \text{InEGR}^2{}_{it} + a_3 \text{InFDS}_{it} + a_4 \text{InTOPE}_{it} + \\ &+ a_5 \text{InGOVE}_{it} + a_6 \text{InURB}_{it} + \sum_{j=1}^{P-1} \lambda^*{}_{ij}\, \Delta \text{InMREN}_{i,t-j} + \sum_{I=0}^{q-1} \delta^*{}_{1j}\, \Delta \text{InEGR}_{i,t-j} + \\ &+ \sum_{I=0}^{q-1} \delta^*{}_{2j}\, \Delta \text{InEGR}^2{}_{i,t-j} + \sum_{I=0}^{q-1} \delta^*{}_{3j}\, \Delta \text{InFSD}_{i,t-j} + \sum_{I=0}^{q-1} \delta^*{}_{4j}\, \Delta \text{InTOPE}_{i,t-j} + \\ &+ \sum_{I=0}^{q-1} \delta^*{}_{5j}\, \Delta \text{InGOVE}_{i,t-j} + \sum_{I=0}^{q-1} \delta^*{}_{6j}\, \Delta \text{InURB}_{i,t-j} + \varepsilon_{it}\end{aligned} \tag{4}$$

3. Results

3.1. Principal Component Analysis (PCA)

PCA was performed to construct a governance quality (GOVE) index. The eigenvalues in Table 3 reveal robust data representation. The first three PCA with eigenvalues greater than one (3.152, 2.383, 1.257) accounted for 84.8% of the total variance, exceeding the 80% threshold.

Table 3. Principal component results

Eigenvalues: (Sum = 6, Average = 1)			
Principal components	Eigenvalues	Percent of variance extracted	Cumulative proportion
1	3.152	0.394	0.3941
2	2.383	0.297	0.6920
3	1.257	0.157	0.8491
4	0.691	0.086	0.9356
5	0.283	0.035	0.9710
6	0.032	0.004	1.0000

Source: authors (2024).

3.2. Cross-Sectional Dependence (CSD)

The Breusch-Pagan LM test and Pesaran CD test confirmed the presence of CSD, as shown in Table 4 (Panel A). This underscores the importance of using second-generation econometric techniques to account for cross-country interaction. The homogeneity test (Panel B) indicates heterogeneity across SSA countries, further validating the methodology.

Table 4. Cross-sectional Dependence Results

Panel A: CSD TEST			Panel B: Homogeneity Test		
Test	Statistic	P-value	Test	Statistic	P-value
Breusch-Pagan LM	80.146	0.0000	$\tilde{\Delta}$	13.590	0.000
Pesaran scaled LM	60.851	0.0000	$\tilde{\Delta}adj$	16.519	0.000
Bias-corrected scaled LM	59.732	0.0000			
Pesaran CD	4.199	0.0000			

Source: authors (2024).

3.3. Panel Unit root tests

The results in Table 5 (Panel A) indicate that the variables are stationary and integrated with mixed orders I (1) and I (0) but not I (2). This implies that the variables did not exhibit significant trends over time after the differences. Panel B reports that all VIF values are below 10, indicating the absence of multicollinearity in the model and ensuring reliable coefficient estimates.

Table 5. Unit Root Results

Panel A: Unit Root					Panel B: Multicollinearity
	CIPS		CADF		VIF
	I(0)	Δ	I(0)	Δ	2.900
FSD	–4.501*	–9.313**	–3.500**	–5.384**	1.800
EGR	–1.417	–7.110**	–3.623**	–5.011**	2.460
EGR^2	–3.231**	–5.101**	–2.912	–7.911**	5.812
TOPE	–2.413*	–7.218**	–1.101	–4.145**	2.020
GOVE	–3.521**	–5.120**	–2.082	–6.047**	4.690
URB	–4.411**	–8.218**	–4.808**	–5.719**	5.210
MREN	–4.220*	–6.813**	–5.940**	–8.003**	1.010

* Depicts 1% significance and ** 5% significance.

Source: author (2024).

3.4. Cointegration test

The cointegration test results in Table 6 (Panel A) reject the (H_0) of no cointegration, indicating the existence of a long-term nexus among FSD, EGR, TOPE, GOVE, URB, and MREN consumption across the panel data. The diagnostic tests (Panel B) confirm the absence of heteroscedasticity, serial correlation, and non-normality, thus ensuring the robustness of the model.

Table 6. Cointegration Test Results

Panel A: Cointegration Test			Panel B: Diagnostics Tests Results	
Statistics	Value	Prob…	Tests	Prob…
Pedroni test			Heteroskedasticity	0.782
H_0: No cointegration; H_1: Cointegration			Serial correlation	0.213
Modified Phillips-Perron regression	3.429	0.001**	Normality	0.830
Phillips-Perron	3.451	0.000**	*The prob-values of the diagnostics test results are non-significant, inferring the absence of heteroskedasticity, serial correlation, and normality of the series*	
Augmented Dickey-Fuller	6.012	0.000**		
Kao test				
H_0: No cointegration; H_1: Cointegration				
Modified Dickey-Fuller *t*	–8.912	0.000**		
Dickey-Fuller *t*	–5.141	0.000**		
Augmented Dickey-Fuller *t*	–6.234	0.000**		
Unadjusted modified Dickey-Fuller *t*	–8.120	0.000**		
Unadjusted Dickey-Fuller *t*	–6.301	0.000**		

** Significance at 0.05% level.

Source: authors (2024).

3.5. Short-Run and Long-Run PMG-ARDL results

The empirical results presented in Tables 7 and 8 focus on three key objectives: (1) the role of GOVE; (2) testing the REKC framework in SSA; and (3) assessing the impact of FSD on MREN across SSA regions.

Table 7. Regional Results

Dependent Variable = MREN					
Coefficient	SSA	West Africa	East Africa	Southern Africa	Central Africa
Short-Run estimate					
FSD	0.295**	0.291**	–1.111**	0.711**	0.601**
EGR	–0.513**	– 0.430**	–0.219**	–0.290**	–0.190**
EGR^2	0.154 **	0.408**	0.700 **	0.723**	0.503**
TOPE	–0.776**	0.7010**	0.513*	–0.073**	–0.145**
GOVE	–1.332*	–0.721**	–0.6231**	–0.710**	–0.110**
URB	–1.571*	0.810**	–0.320**	0.422**	–0.029*
CointEq(–1)*	–0.758**	–0.450**	– 0.701**	–0.806**	–0.300**
Hausman Test (P-value)	0.045 (0.431)	0.023 (0.219)	0.017 (0.712)	0.212 (0.321)	0.157 (0.981)
Long-Run estimate					
FSD	0.530**	0.620**	0.187*	–0.036**	0.016**
EGR	0.238**	0.843**	0.671**	0.730**	0.585**
EGR^2	0.243**	–0.573**	0.747**	–0.540*	–0.467**
TOPE	–0.267*	2.230*	0.731**	0.022*	0.013**
GOVE	–0.530*	0.149**	0.269**	–0.161**	0.833**
URB	0.154**	0.502*	0.045**	0.535**	0.781**

* Statistically significant at the 5% level ($p < 0.05$); ** statistically significant at the 1% level ($p < 0.01$).

Source: authors (2024).

3.6. Country specific results

Table 8. Country specific results

Dependent Variable = MREN						
Coefficient	Nigeria	Ghana	Côte d'Ivoire	Kenya	Ethiopia	Tanzania
Short-Run Estimate						
FSD	–0.916**	0.781**	–0.0187*	–0.036**	0.043*	0.043**
EGR	–0.252**	–0.055**	–0.028**	–0.011**	–0.475**	–0.246**
EGR^2	–0.625**	0.199*	–0.246**	0.198**	0.058**	–0.246**
TOPE	0.706**	0.509**	–0.553**	0.133**	0.241**	0.102**
GOVE	–0.641**	–0.123**	–0.614**	0.017**	–0.165**	0.108**
URB	0.564*	0.505**	–5.411**	–0.764**	0.176**	–0.161**
CointEq(–1)*	–0.303**	–0.8223**	–0.572**	–0.4913**	–0.951**	–0.355**

Continuation of table 8

Coefficient	Uganda	South Africa	Namibia	Botswana	Cameroon	
FSD	0.984**	0.8600**	0.713**	0.348*	0.356**	
EGR	0.984**	0.8600**	0.713**	0.313**	0.910	
EGR^2	2.035**	–7.7870*	0.825**	0.686**	0.307**	
TOPE	0.260*	0.1880*	0.190*	3.515**	0.233**	
GOVE	0.141*	0.1360*	0.260**	0.307**	–0.190**	
URB	–0.382**	–0.1050**	0.141**	0.347**	0.686**	
CointEq(–1)*	–0.824**	–0.5624**	–0.307**	–0.585**	0.307**	
Long-Run Estimate						
Coefficient	Nigeria	Ghana	Côte d'Ivoire	Kenya	Ethiopia	Tanzania
FSD	0.793**	0.9586**	–0.2511*	0.718**	0.704**	0.767**
EGR	–0.706**	0.920**	0.728**	0.552*	0.805**	0.553**
EGR^2	–0.035**	0.654**	0.2045**	0.385**	0.367**	0.777**
TOPE	0.189*	0.219**	0.263**	2.230**	0.178**	0.590**
GOVE	0.102**	0.858**	0.141**	0.245**	0.343**	0.276**
URB	0.149**	–0.245**	0.276**	0.738**	0.236**	3.693**
Coefficient	Uganda	South Africa	Namibia	Botswana	Cameroon	
FSD	0.382**	–0.1054*	0.1411**	0.1366**	0.099**	
EGR	–0.1909*	–0.307**	–0.392*	–0.538**	–0.288*	
EGR^2	0.6148**	0.529**	–0.317**	0.651**	0.347**	
TOPE	0.791**	0.313**	0.957*	0.485**	0.777**	
GOVE	0.260**	0.775**	0.243**	0.359**	–0.823**	
URB	0.943**	0.5109**	–0.848**	0.248*	0.622**	

* Statistically significant at the 5% level ($p < 0.05$); ** statistically significant at the 1% level ($p < 0.01$).

Source: authors (2024).

H_1: GOVE and MREN Adoption

In the short run, GOVE exerts a predominantly negative influence on MREN across the SSA regions (–1.332), indicating that poor GOVE significantly hampers the financial mobilization essential for MREN investment. This detrimental impact is particularly evident in West Africa (–0.721), East Africa (–0.623), and Southern Africa (–0.710), where inefficiencies, corruption, and weak regulatory frameworks obstruct MREN investment. In contrast, the long-run shows a positive link between GOVE and MREN in West Africa (0.149), East Africa (0.269), and Central Africa (0.833). The country-specific results show that Nigeria's weak governance significantly hinders MREN adoption in the short run (–0.641, $p < 0.01$), but governance reforms improve MREN consumption in the long run (0.102, $p < 0.01$). Conversely, Ghana (0.858, $p < 0.01$), Kenya, and Uganda demonstrated positive long-term effects of GOVE, indicating that governance reforms in these nations foster an enabling environment for sustainable energy development. In contrast, Cameroon experiences a negative long-term impact (–0.8237, $p < 0.01$), which highlights the persistent GOVE challenges undermining MREN initiatives due to systemic inefficiencies and corruption. These results align with those of earlier studies (Inim et al., 2024; Udo et al., 2024) but diverge from Habiba and Xinbang (2023), and Rosemary et al. (2021) who reported a positive short-term impact of governance on MREN in other regions.

H_2: Testing the REKC Framework

The REKC hypothesis posits a U-shaped bond between EGR and MREN, which is confirmed in this study. In the short run, EGR negatively affects MREN across SSA (–0.513), indicating an initial reliance on non-renewable energy sources during the early stages of development. West Africa (–0.430) and East Africa (–0.219) demonstrate this trend most strongly.

However, in the long run, the positive coefficient for the squared term of EGR (EGR^2) indicates a transition toward MREN as economies mature, thus confirming the U-shaped relationship. East Africa (0.700) and Southern Africa (0.723) displayed strong long-term transitions to MREN, particularly in geothermal and hydropower initiatives in Kenya and Ethiopia. The country-level results reveal that Nigeria and Côte d'Ivoire follow the REKC trajectory, where economic growth initially accelerates emissions, but MREN adoption increases as economies surpass a critical income threshold. Ghana (0.654) and Ethiopia show positive EGR^2 coefficients, confirming the inverted U-shaped REKC, whereas Kenya and Tanzania further support the REKC framework with consistent positive EGR^2 values. These results align with those of Udo et al. (2025), Enemuo et al. (2025), Yao et al. (2019) and Gielen et al. (2019) but differ from those of Skare et al. (2023), who found no evidence of the REKC in other regions, emphasizing the context-specific nature of this association in SSA.

H_3: FSD influence on MREN

The influence of FSD on MREN varied significantly across SSA regions. In the short run, FSD had a positive impact on MREN in SSA (0.295), with more pronounced effects in West Africa (0.291) and Southern Africa (0.711), where relatively developed financial markets facilitate investment in solar and hydropower projects. However, East Africa experienced a negative short-run effect (–1.111), signifying challenges in efficiently channelling financial resources to large-scale MREN projects. In the long run, FSD contributes positively to MREN in West Africa (0.620) and East Africa (0.187), indicating a gradual alignment between financial systems and REN goals. Country-specific results demonstrate that in West Africa, Nigeria, and Côte d'Ivoire initially prioritize fossil fuel investments, in line with the Pollution Haven Hypothesis. Ghana, however, shows positive FSD impacts, indicating effective financial market mobilization for MREN technologies. East Africa, particularly Kenya (0.718), shows positive short- and long-term FSD effects, driven by investments in wind and geothermal power. Southern African countries such as South Africa and Namibia also exhibit positive long-term FSD effects, reflecting the capacity of advanced financial markets to support MREN investments. These results align with those of Udo et al. (2025) and Ndubuaku, et al. (2021).

3.7. Error correction results

The negative and statistically significant CointEq. (–1) values reveal SSA countries and subregion adjustments toward long-run equilibrium at varying speeds after short-term shocks. Southern Africa shows the fastest adjustment (6–7 months, ~80.6%), reflecting a more responsive system, while Central Africa's slower adjustment (~9 months, ~30%) indicates a lower adaptability. This highlights the regional differences in the implementation and response to energy and governance policies. The study confirms that FSD and GOVE are essential drivers of MREN adoption, supporting MRENEKC in the long run.

3.8. Regional comparison of MREN adoption in the SSA region

West Africa (Nigeria, Ghana, Côte d'Ivoire)

In West Africa, FSD exerts a positive effect on MREN adoption in both the short-long term. In Nigeria, the solar and hydropower sector expansion is supported by GOVE improvement, although its industrial base and high emissions complicate the MREN transition. Ghana clearly benefits from FSD by implementing effective policies to drive renewable energy investments. Côte d'Ivoire reflects mixed outcomes with both positive and negative FSD impacts, suggesting variability in investment success across the region.

East Africa (Kenya, Ethiopia, Tanzania, Uganda)

East Africa has complex FSD dynamics. While FSD negatively affects MREN adoption in the short term, the region has long-term potential, especially for geothermal and wind energy. Kenya and Tanzania are leaders in MREN adoption with growing financial inclusion and diversification efforts, particularly in Kenya's focus on geothermal energy. These trends emphasize the key role of financial markets in supporting REN investments.

Southern Africa (South Africa, Namibia, Botswana)

South Africa's advanced financial systems have not fully translated into substantial MREN growth. Despite the robust financial markets in South Africa supporting green energy projects, the region faces challenges in transitioning from fossil fuels. Namibia and Botswana show positive FSD effects on MREN, indicating future growth potential as the financial systems evolve.

Central Africa (Cameroon)

In Central Africa, Cameroon exhibits positive long-term governance (GOVE) effects on MREN but faces challenges due to governance inefficiencies. These issues limit the effectiveness of FSD in promoting MREN, as shown by the negative correlations between GOVE and economic growth rates (EGR). Governance reforms are essential for scaling MREN efforts in the region.

These findings confirm the applicability of the MRENEKC framework across the SSA. FSD and GOVE are key drivers of MREN adoption, although regional differences require tailored policies. This study emphasizes the need for financial market reforms, governance improvements, and specific energy strategies to promote sustainable development in SSA, offering novel insights into the role of GOVE and FSD in the region's REN transitions.

Conclusions and policy recommendations

This study assessed the interplay between FSD, GOVE, and MREN adoption across 11 Sub-Saharan African (SSA) countries from 1999 to 2024, testing the validity of the MRENEKC hypothesis. The results from PCA, panel cointegration, and PMG-ARDL model estimations, confirms the applicability of the MRENEKC framework in SSA, revealing a U-shaped nexus between EGR and MREN adoption. In the short run, EGR is negative (–0.513 for SSA overall), indicating that EGR initially hinders MREN adoption due to dependency on fossil fuel for industrialization. In the long run, as the economy evolves with improvement in GOVE and income level EGR^2 positively across all subregions (0.700 in East Africa, 0.723 in Southern Africa) encourages MREN adoption, reflecting a U-shaped nexus, this is evident in countries like Kenya, Ghana, and Ethiopia.

The study results revealed the dual role of GOVE, thus in the short run, lax governance significantly hinders MREN adoption across most regions with negative coefficients for SSA (–1.332), West Africa (–0.721), East Africa (–0.623), and Southern Africa (–0.710). However, in the long run, improvements in governance through regulatory stability, control of corruption, and rule of law positively influence MREN investment and sustainability in West Africa (0.149), East Africa (0.269), and Central Africa (0.833). This implies that while regulatory instability and corruption hinder immediate progress, sustained governance reforms ultimately create an enabling environment for renewable investment.

The results also reveal that FSD influence is heterogeneous across regions, as such FSD positively influence MREN adoption in West Africa (0.620 long-run) and Southern Africa (0.711 short-run), this implies that investment in financial markets development can facilitate solar and hydropower investments. In East Africa, FSD shows a negative short-run effect (–1.111), reflecting financing barriers for capital-intensive projects, the positive long-run effect (0.187) reveals strong potential once structural constraints are addressed. At the country level, Kenya (0.718) and Ghana (0.958) show strong positive FSD–MREN links.

TOPE and URB produce mixed results, thus TOPE strongly supports MREN adoption in West Africa (2.230 long run) and Kenya (2.230), due to technology transfer and renewable equipment imports, but is less effective or negative in fossil-dependent economies. URB supports MREN in Southern Africa (0.535) but shows neutral or adverse effects elsewhere, possibly due to infrastructure gaps and continued fossil reliance. The adjustment speed, captured by error correction terms, varies as Southern Africa adjusts to equilibrium in about 6–7 months (–0.806), this implies that financial system development contributes to MREN transitions. In Central Africa it requires about 9 months (–0.300), reflecting differences in policy responsiveness. As such Cameroon faces governance inefficiencies that undermine FSD's impact. These results revealed that while SSA is diverse, regional cooperation, institutional strengthening, and financial deepening can jointly accelerate an inclusive energy transition. These results inform evidence-based policy recommendations as such:

1. **Strengthening governance frameworks**. The negative short-run and positive long-run GOVE influence reveal that addressing corruption, enhancing regulatory stability, and reinforcing institutional capacity are prerequisites for sustained MREN growth. Regional bodies such as the African Union (AU) and ECOWAS can facilitate governance reforms and knowledge exchange especially in governance-challenged states to effectively promote MREN adoption.

2. **Enhancing financial sector development**. Positive FSD effects in West and Southern Africa and strong country-level results for Kenya and Ghana support policies that expand green financing instruments, such as green bonds and concessional loans, while also addressing short-term financing barriers in East Africa to unlock geothermal and wind potential. Strengthening public-private partnerships and implementing financial literacy programs are also vital to expanding MREN infrastructure for REN adoption.
3. **Aligning growth strategies with MREN objectives**. The confirmed U-shaped EGR–MREN nexus indicates that countries should integrate renewable targets into economic planning, focusing on low-carbon sectors to accelerate the transition past the REKC turning point.
4. **Trade and investment reform**. Positive TOPE–MREN nexus in some regions support policies to reorient trade and FDI toward renewable technologies, streamline import tariffs on clean energy equipment, and embed renewable technology transfer incentives in trade agreements like AfCFTA
5. **Tailor regional energy policies**. Regional institutions should design energy policies tailored to address local challenges and resource potentials. As such Southern Africa's rapid adjustment speed allows for quick scale-up of existing programs, West Africa should prioritize industrial decarbonisation through finance-led MREN growth, East Africa should focus on unlocking large-scale geothermal and wind investments, and Central Africa must improve governance before FSD can be fully effective.

The study results reveal that governance quality and financial sector depth are the primary levers for accelerating SSA's renewable transition, while the MRENEKC results confirm that economic growth alone will not ensure environmental sustainability. Structural reforms in governance, finance, trade, and regional cooperation are essential to achieving an inclusive, low-carbon energy future for the region.

Although this research was conducted with a high level of methodological rigor and quality, certain limitations remain. The study relies on aggregated regional and national datasets, which, while robust, may mask intra-country variations and sector-specific dynamics. Additionally, while the PMG-ARDL and PCA methods capture long-run and short-run effects effectively, they cannot fully account for unobserved political or environmental shocks that may influence MREN adoption. These limitations do not detract from the validity of the findings but indicate opportunities for future research to use more granular, sectoral, or spatially disaggregated data and to incorporate emerging factors such as climate finance flows, technology innovation rates, and political stability indices.

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