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Funding the Green Transition: Governance Quality, Public Debt, and Renewable Energy Consumption in Sub-Saharan Africa

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Funding the Green Transition: Governance Quality, Public Debt, and Renewable Energy Consumption in Sub-Saharan Africa

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Abstract

Prompted by the renewable energy funding challenge in sub-Saharan Africa (SSA) amid surging public debt in the region, this study investigates the moderating role of governance quality in the relationship between public debt and REC in the region using the Feasible Generalized Least Squares. The study established that public debt positively impacts REC, but the interactive effect of governance quality and public debt impedes REC. Policy prescriptions are put forward to address the funding challenges of transitioning to a green energy future in SSA by highlighting the critical role of governance.

Keywords: Public Debt, Renewable Energy Consumption, Governance Quality, Sub-Saharan Africa

1. Introduction

Electricity uses in sub-Saharan Africa (SSA) will more than triple in the next two decades, with a bleak chance of gaining more access to grid-based electricity (IEA, 2019). Rapid population expansion will be the primary driver of the increase in energy demand (Dimnwobi et al., 2021). Between 2022 and 2050, the region's population is predicted to roughly double, topping 2 billion people by the late 2040s. It is also anticipated that between 2022 and 2050, SSA will account for over half of the increase in the global population (United Nations, 2022). Renewable energy offers a way out of the energy crisis that several SSA nations are experiencing (Dimnwobi et al., 2022a; Dimnwobi et al., 2022b). It is an appealing alternative to the current situation for various reasons. First, because of technological advancements, wind, and solar energy are now less expensive than energy generated from traditional fossil fuels or nearly at cost parity (IEA, 2019; Olabisi et al., 2022). SSA has a far greater energy potential for these sources (IEA, 2019). With the correct investments, the cost of renewable energy infrastructure might be reduced, allowing nations to “leapfrog” to distributed energy systems, much like SSA nations did when switching from landlines to mobile phones (Levin & Thomas, 2016). Second, even after considering the intermittent and variable nature of solar and wind energy, fossil fuel prices are increasing and are more volatile relative to renewable energy systems, which seem to have more predictable cost trends.

Additionally, renewable energy sources tend to be more realistic for off-grid rural or isolated places where access to electricity continues to be a major challenge (Adelaja, 2020; Li & Haneklaus, 2021; Olabisi et al., 2022; Tutak & Brodny, 2022). Massive investments will be needed over the next two decades to supply energy in the region as it is anticipated that by 2040, the demand for electricity in Africa will rise from 700 to 1600 terawatt-hours (TWh) annually (IEA, 2019). A report by African Energy Outlook estimates that between 2019 and 2040, annual energy investments totaling $120 billion would be needed to supply Africans with electricity access (IEA, 2019).

In order to achieve sustainable development goals, developing countries require considerable investments in various areas such as facilities, human resources, and climate change resiliency. However, these nations face limitations in their ability to generate public or private funding, and resorting to debt to finance development needs has led to unsustainable levels that hinder economic progress. Renewable energy deployment requires financial resources, but its higher cost than conventional sources poses a challenge (Anton & Nucu, 2019; Dimnwobi et al., 2022a). Governments borrow to build infrastructure considered essential for accelerating the economy's expansion when domestic investment and foreign exchange earnings fall short of meeting national developmental goals (Onafowora & Owoye, 2017). Global public debt has increased since the 1970s as countries borrow to address fiscal gaps, with Sub-Saharan Africa's public debt surging from 26.7% to 57.8% of GDP between 2010 and 2020 (IMF, 2021). The duo of HIPC debt relief initiatives and the Multilateral Debt Relief Initiatives (MDRI) debt relief programs played a significant role in this trend (Mupunga & Ngundu, 2020). The reduction of debt and improved economic conditions, coupled with favourable global liquidity and growth rates, have provided African nations with fiscal space to borrow money for infrastructure and development projects (IMF 2015). The positive macroeconomic environment, supported by rising global commodity prices, has also improved their creditworthiness (Okafor et al., 2022). Additionally, expanding domestic financial markets in various African nations and increasing lending activity by non-Paris Club nations have provided more borrowing options in the global capital markets (IMF, 2015). As a result, public debt has been increasingly used as a funding source for environmental programs in addition to its traditional role in public sector economics literature (Hashemizadeh et al., 2021).

Institutions of governance are critical for public borrowing, sustainability, and economic outcomes. Public borrowing could be beneficial or harmful; when utilized prudently, a nation may benefit from borrowing; when utilized imprudently and excessively, however, a nation may become ensnared in a huge debt burden (Sandow et al., 2022). Meanwhile, the criticality of governance quality has gained prominence because it explains why nations with comparable borrowing levels have differing infrastructure and economic outcomes (Tarek & Ahmed, 2017; Sandow et al., 2022). According to Megersa and Cassimon (2015), nations with effective governance are likely to make better use of external resources, such as public borrowing. Bouchrara et al. (2020) and Acheampong et al. (2022) discovered that public borrowing undermines the achievement of positive outcomes in nations with poor governance. They contend that nations with less effective institutions may borrow more than nations with stronger institutions. In most circumstances, nations with weak institutions may divert loans from their original purpose and towards sectors more prone to theft. This problem indicates that public borrowing alone cannot ensure sustainable economic outcomes in the absence of effective governance(Butkus & Seputiene, 2018)

Public debt can have both direct and indirect effects on renewable energy deployment and development. The direct effect of government debt is predicated on an assumption that the government utilizes debt to support renewable energy deployment and development projects and provide funding for renewable energy technology research (Farooq et al., 2023). Furthermore, rising debt levels may force the government to reduce investments and spending to bridge budget deficits. As a result, investment in renewable energy sources may be reduced (Alhassan &Kwakwa, 2022; Farooq et al., 2023). Through economic expansion, public borrowing indirectly influences renewable energy development and end-use adoption. This is possible since public debt promotes capital inflows, encourages investment, and improves economic performance. Hence, increased economic growth may contribute to greater demand for modern energy sources (Dimnwobi et al., 2023). The ability to afford sustainable energy resources is predicted to improve as income rises (Farooq et al., 2023)

In light of the background information provided, the primary research questions are: (1) Does public debt influence renewable resource usage in SSA, and if these impacts differ across SSA sub-regions? (2) Does governance quality moderate the relationship between SSA's public debt and renewable energy consumption (REC)? This study adds to the body of existing literature in three key respects. First, as far as we know, limited empirical research has addressed the link between public debt and REC in Africa, especially in a panel analysis. Moreover, SSA member countries have also not paid much attention to these factors. The current study, which is the first to examine the relationship between public debt and REC in 29 SSA nations, fills this gap. Second, we investigated the moderating role of governance quality because it influences both the distribution of borrowed funds and the level of debt. Prior research focused on the relationship between debt growth and governance quality (Butkus & Seputiene, 2018; Bouchrara et al., 2020; Shittu et al., 2020; Kemoe & Lartey, 2021; Sandow et al., 2022). Third, to do a comparative analysis, this study develops four additional sub-panels: a panel of five Central African economies, a group of six East African member states, a cluster of thirteen West African economies, and a group of five Southern African economies. This study analyzes these sub-panels separately and checks for patterns in the empirical analysis.

This study is broken into the following sections: Section 2 provides documentation of the review of the existing literature, while Section 3 provides information on the methodology and data. The primary findings and conclusion are presented in Sections 4 and 5, respectively.

2. Literature Review

The theoretical literature on the relationship between public borrowing and economic outcomes is equivocal. The study emphasizes the key points made in the literature. One such theoretical perspective is the neo-classical school which avers that government borrowing undermines private investment, which has a detrimental influence on capital accumulation and economic outcomes. They argue that policies discourage investment and economic outcomes because the government is inherently bureaucratic and ineffective. The Keynesian view of public debt, on the other hand, supports public borrowing. Keynesianism stresses that during an economic slump, the state is called upon to augment market efforts, address market shortcomings, promote economic expansion, and stop the economic downturn (Olaoye et al., 2022). They argue that increasing government expenditures through debt can stimulate economic expansion by assuring efficient resource allocation, effective market regulation, economic stabilization, and resolution of social conflicts (Keynes, 1936).

Debt overhang theory is another theoretical argument pioneered by Krugman (1988). There is a debt overhang when the growth of public debt produces negative externalities that are more significant than the economic resource transfer considering that both local and international investors anticipate future tax increases and economic uncertainties, which discourages investment in the debtor nation and lowers private investment (Olaoye et al., 2022). The public choice theory offers an additional theoretical foundation for understanding public borrowing and its effects on economic outcomes. According to the thesis, every society is defined by self-interested individuals seeking to maximize their interests at the expense of society (Sandow et al., 2022), which explicates the frequent overestimation of budgets by governmental officials (Blum et al., 2012). According to Megersa and Cassimon (2015), government officials in developing nations have a strong inclination to divert public funds for personal gains, which may result in unsustainable debt levels and lower economic outcomes.

Focusing on some of the emerging economies in the European Union, Florea et al. (2021) appraised the influence of public borrowing on REC and discovered that public borrowing encourages the use of renewable energy. Analogously, Przychodzen, and Przychodzen (2019) evaluated the variables affecting renewable energy production in 27 transition economies between 1990 and 2014. The study identified public borrowing as one factor that boosts renewable energy generation. However, some studies in the extant literature highlighted that public borrowing undermines the utilization of renewable energy. For instance, a Hashemizadeh et al. (2021) study for selected emerging nations reported that governmental debt reduces REC.

In a similar study of BRICs nations, Wang et al. (2020) revealed that a higher level of public borrowing might lead to less public investment in the renewable energy industry and decreased REC. Likewise, in Asian economies, Jianhua (2022) revealed that a decline in the utilization of REC is correlated with rising public debt.

On the other hand, the role of debt on environmental pollution has also been investigated in the literature. For instance, Alhassan and Kwakwa (2022) revealed that ecological decay is first reduced by public borrowing, but once the debt has doubled, ecological decay grows. Likewise, Qi et al. (2022) reported that debt facilitates significant reductions in urban pollution levels in China. In a related study of selected emerging nations, Sadiq et al. (2022) discovered that foreign borrowing promotes environmental sustainability. Akamet al. (2021a) employed data from four African nations from 1970 to 2018 and highlighted that foreign debt has no substantial influence on environmental quality. Similarly, Akam et al. (2021b) highlighted that environmental decay is not significantly caused by foreign debt in 33 debt-ridden economies. In a related study in Turkey, Katircioglu and Celebi (2018) revealed that foreign borrowing has no significant influence on environmental deterioration.

Aside from public borrowing, the literature also shows several other factors influencing REC. The factors can be grouped into economic factors (economic growth and financial development) and demographic factor (urbanization). For instance, Mukhtarov et al. (2020), Gozgor et al. (2020), Zhao et al. (2020,) and Oluoch et al. (2021) highlighted that economic growth promotes REC while Asongu and Odhiambo (2020), Qamruzzaman and Jianguo (2020), Khan et al. (2020) and Dimnwobi et al. (2022a) documented that financial advancement boosts REC. Similarly, Akintande et al. (2020), Baye et al. (2021), and Bayale et al. (2021) reported that urbanization facilitates the utilization of renewable energy.

3. Data and Methodology

3.1. Data

The estimations are based on data from a panel of 29 SSA nations (see Appendix 1) from 1996 to 2020. Data availability for all the variables informed the decision to use this periodicity. Crucially, the dependent variable is REC, while the primary independent variable is public debt.

The governance environment is represented by six governance quality indicators provided by World Governance Indicators (WGI): government effectiveness, voice and accountability, regulatory quality, control of corruption, the rule of law and political stability, and absence of violence. They are graded on a scale of (-2.5; 2.5), with higher values indicating more effective governance. Public debt is negatively impacted by less effective governance. Governance infrastructure enables the government to manage its debt more effectively while lowering its overall level. We employed three control variables: financial development, economic growth, and urbanization, consistent with previous related studies (Wang et al., 2020; Hashemizadeh et al., 2021; Jianhua, 2022). All the variables were collected from the World Bank World Development Indicators (WDI) except the governance variables obtained from World Governance Indicators and public debt, which came from the International Monetary Fund's (IMF) Public Debt Database. Table 1 briefly explains the variables and their sources

Table 1: Variables Data and Sources

Variables	Symbol	Sources
Public debt (% of GDP)	PD	IMF Data
Renewable energy consumption (% of overall final energy consumption)	REC	WDI Data
Financial development (Domestic private sector credit as a % of GDP)	FD	WDI Data
Gross Domestic Product Per Capita (Constant 2010 US$)	GDPC	WDI Data
Urbanization (% urban in the overall population)	UBZ	WDI Data
Control of corruption	CCR	WGI Data
Government effectiveness	GES	WGI Data
Voice and accountability	VAA	WGI Data
Political stability and absence of violence	PSA	WGI Data
Regulatory quality	RQL	WGI Data
Rule of law	RLW	WGI Data

Source: Authors Computation

3.2. Model development

To attain the objectives of this empirical adventure, we follow the similar empirical submission of Alola et al. (2022); Dimnwobi et al. (2022b); Muoneke et al. (2023) and present a dynamic panel model in equation 1 incorporating the interaction term $(pd * GQ)$, which facilitates the evaluation of the interaction effect of both public debt and governance quality indicators.

$$REC_{it} = \alpha_0 + \beta pd_{i,t} + \theta GQ_{i,t} + \lambda(pd_{i,t} * GQ_{i,t}) + \gamma Z_{it} + \varepsilon_{it} \quad (1)$$

Where REC= Renewable energy consumption, pd=Public debt, Z = vector of control variables (Financial development, Gross Domestic Product Per Capita, Urbanizationε_{it} = general error term; the parameter estimates that informed this study are $\delta, \beta, .\alpha_0$=intercept of the model, $i = 1 \dots . N$ is the number of cross-sections, t depicts the period. From Equation 1,λ depicts whether the interaction of GQ on pd strengthens or deters the impact of pd on REC. Intuitively, if $\lambda$is positive, governance quality complements the impact of public debt on renewable energy.

3.3. Estimation Approach

Before engaging the econometric analyses, it becomes imperative to subject the data to some pre-estimation checks such as (1) cross-sectional dependence, (2) stationarity, and (3) cointegration tests. Failure to control for cross-sectional dependence (CSD) can result in biased estimates due to high dependence across countries (Pesaran, 2004, 2015). The CSD test is suited for both balanced and unbalanced data, and the null hypothesis is weak cross-sectional dependence (Pesaran, 2015) against the alternative hypothesis of strong cross-sectional dependence. If cross-sectional dependence is evident in the data, the study applies CIPS panel unit root tests. Correspondingly, we employed the Pederon test and the second-generation Westerlund (2007) cointegration test suited for heterogeneous and cross-sectionally dependent panels is applied. The null hypothesis of no cointegration can be rejected if the variables are cointegrated in all or some of the panels.

A method proposed by Westerlund (2007), which accommodates the presence of CD, is used to examine the presence of a long-run relationship between the variables. The error-correction equation takes the form:

$$\Delta Y_{i,t} = \mu_i' d_t + \omega_i \left(Y_{i,t-1} - \beta_i' X_{i,t-1} \right) + \sum_{j=1}^{k} \emptyset_{ij} \Delta Y_{i,t-j} + \sum_{j=1}^{k} \gamma_{ij} \Delta X_{i,t-j} + \varepsilon_{i,t} \qquad (2)$$

where ω_iTheerror-correction term's coefficient indicates the correction speed towards equilibrium, Y_{it} and X_{it} are dependent and explanatory variables, respectively. Four (4) statistics can be derived from Equation (2):

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\widehat{\omega_i}}{se(\widehat{\omega_i})} \qquad (3)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\omega_i}}{1-\sum_{j=1}^{k}\omega_{ij}} \quad (4)$$

$$P_t = \frac{\widehat{\omega}}{se(\widehat{\omega})} \quad (5)$$

$$P_a = T\widehat{\omega} \quad (6)$$

Where statistics $G_t$andG_a provide the basis for testing the existence of cointegration in at least one cross-sectional group while thestatistics $P_t$andP_a, test for cointegration in the entire panel.Accordingly, the feasible generalised least square (FGLS) method, first described by Parks (1967) and later popularized by Kmenta (1986), is an algorithm-based approach. The performance of this model lies in its ability to account for variations in the standard errors of the slope coefficients by using cross-sectional discrepancies. Time-series autocorrelation, cross-sectional autocorrelation, and cross-sectional heteroscedasticity can also be easily managed with the configuration (Sial et al., 2022). In the asymptotic regime where N and T are both big, the consistency of the uncorrected estimator makes the necessity for bias correction less apparent.

Given that an estimate occurs in the estimator of the variance of the FGLS estimator, it seems logical to assume that adopting a bias-corrected estimate would lower the bias in the estimate of the variance of the FGLS estimator. In a further analysis, the Prais-Winsten regression model with panel-corrected standard errors is used for robustness tests and for monitoring the consistency of the results. For the sub-samples, we adopted the Augmented mean group (AMG) estimator proposed by Eberhardt and Bond (2009), which addresses the problem of cross-sectional dependence and a heterogeneous panel data set using a common dynamic process, because panel data estimation presents several econometric issues that affect the validity of the parameters, AMG produces an unbiased and effective parameter estimate even in the absence of nonstationary data. This estimator is used to run further simulations for the research. AMG estimator, proposed by Eberhardt and Teal (2010), is also robust to the CD and slope heterogeneity. Against the setup in the FGLS estimator and Prais-Winsten regression model, the AMG, in line with economic theory, treats unobservable common factors with a particular interest in the sub-samples. The first difference estimates a pooled regression model augmented with time dummies to implement the AMG algorithm(Eberhardt and Teal, 2009). This initial step takes the form of the following equation:

$$Y_{it} = \rho_i + \alpha_i \Delta X_{it} + \tau_i \delta_t + \sum_{t-1}^{T} \phi_t D_t + \varepsilon_{it} \qquad (7)$$

Where, α_i is introduced as the slope, δ_t as the unobserved common factor, τ_i as the heterogeneous factor loadings, D_t and ϕ_t are the year dummies and their coefficients, respectively. In the second stage of the empirical setup, the group-specific regression specification is augmented by allocating a unit coefficient to each group unit, and the group-specific parameters are averaged across the panel.

$$AMG = \frac{1}{N} \sum_{i=1}^{N} \widehat{\alpha_i} \qquad (8)$$

4. Empirical results and discussion

4.1. Preliminary Results

Tables 2A and B contain descriptive statistics and correlation matrices of the raw data for the four sub-regions (Central Africa, East Africa, Southern Africa, and West Africa) in our study, which report the common properties of the variables used. The series indicates that the mean values of the variables in all four sub-regions are higher than their corresponding median values, further implying that the distributions of the variables are asymmetrical and not symmetrical. Hence some variables are skewed to the right, while others are skewed or biased to the left. The standard deviation was used in comparison with the mean; as such, the coefficients of the standard deviations are smaller than the mean in all the sub-samples to confirm if the mean appropriately represents the data, meaning that the data tend to cluster or concentrate around the mean. In other words, no significant deviation from the mean in the actual data shows that the mean values accurately reflect real-world data. In all the sub-regions, some variables indicate leptokurtic (those with their kurtosis >3), and others exhibit platykurtic (those with less than 3) distribution. The lower part of each subsample displays the correlation result, which was employed to test the degree of a linear relationship between the variables. The negative coefficients of correlation between REC and all other variables in all the regions except for the case of West Africa (where PD exhibits a positive correlation with REC) entail an inverse and linear association.

Table 2A: Descriptive statistics and correlation for Central and East Africa

Descriptive	CENTRAL AFRICA										
	REC	PD	FD	GDPC	UBZ	CCR	GES	PSA	VAA	RQL	RLW
Mean	80.950	68.841	8.664	2977.099	51.524	-1.134	-1.098	-0.902	-1.053	-0.956	-1.134
Median	78.950	61.008	8.352	1278.596	50.350	-1.167	-1.130	-0.977	-1.060	-1.050	-1.177
Maximum	98.089	264.443	19.189	11949.28	90.092	-0.327	0.047	0.704	-0.321	0.466	-0.125
Minimum	54.800	9.715	2.010	334.441	21.506	-1.534	-1.887	-2.699	-1.581	-1.584	-1.841
Std. Dev.	9.958	49.208	3.924	3496.671	21.229	0.237	0.372	0.760	0.257	0.398	0.386
Skewness	-0.601	1.682	0.179	1.364	0.202	0.923	0.258	0.167	0.598	1.477	0.704
Kurtosis	2.756	6.225	2.181	3.217	2.007	3.709	2.796	2.190	3.616	5.200	3.035
Jarque-Bera	7.842	113.137	4.161	39.014	5.989	20.400	1.609	3.993	9.444	70.674	10.336
Probability	0.019	0.000	0.124	0.000	0.050	0.000	0.447	0.135	0.008	0.000	0.005
Correlation											
REC	1.000										
PD	-0.250	1.000									
FD	-0.016	-0.168	1.000								
GDPC	-0.199	-0.036	0.306	1.000							
UBZ	-0.340	0.088	0.476	0.848	1.000						
CCR	-0.042	0.036	0.279	0.680	0.689	1.000					
GES	0.084	-0.037	0.140	0.606	0.502	0.479	1.000				
PSA	-0.012	-0.006	0.008	0.579	0.469	0.581	0.628	1.000			
VAA	-0.317	-0.119	0.250	0.808	0.757	0.525	0.733	0.566	1.000		
RQL	-0.050	-0.174	0.145	0.774	0.535	0.603	0.706	0.723	0.696	1.000	
RLW	-0.162	-0.138	0.289	0.852	0.725	0.713	0.767	0.701	0.845	0.820	1.000
Descriptive	EAST AFRICA										
Mean	68.335	70.574	16.667	2477.929	26.319	-0.475	-0.644	-0.599	-0.577	-0.597	-0.615
Median	61.785	58.362	15.623	847.704	24.299	-0.739	-0.640	-0.463	-0.557	-0.472	-0.748
Maximum	96.040	202.051	44.513	14232.61	57.546	1.420	0.727	0.486	1.340	0.682	0.857
Minimum	0.710	18.145	2.940	202.372	7.412	-1.544	-1.809	-1.724	-2.522	-1.713	-1.616
Std. Dev.	32.054	40.347	8.388	3950.298	13.759	0.707	0.746	0.546	0.929	0.550	0.612
Skewness	-1.38	1.110	0.437	1.904	0.908	0.882	0.318	-0.347	0.038	-0.049	0.515
Kurtosis	3.382	3.800	2.858	4.951	2.918	2.543	2.122	2.006	2.155	2.067	2.367
J-BERA	48.578	34.845	4.905	114.493	20.666	20.768	7.352	9.197	4.492	5.498	9.154
Prob	0.000	0.000	0.086	0.000	0.000	0.000	0.025	0.010	0.105	0.063	0.010
Correlation											
REC	1.000										

PD	-0.360	1.000									
FD	-0.945	0.392	1.000								
RGDPC	-0.922	0.278	0.901	1.000							
UBZ	-0.684	0.235	0.758	0.676	1.000						
CCR	-0.650	0.451	0.733	0.678	0.802	1.000					
GES	-0.658	0.292	0.625	0.813	0.371	0.504	1.000				
PSA	-0.760	0.030	0.698	0.827	0.716	0.658	0.653	1.000			
VAA	-0.760	0.030	0.698	0.827	0.716	0.658	0.808	0.840	1.000		
RQL	-0.519	0.513	0.561	0.573	0.652	0.902	0.494	0.898	0.628	1.000	
RLW	-0.684	0.260	0.715	0.757	0.833	0.898	0.628	0.731	0.623	0.612	1.000

Source: Authors Computation

Table 2B: Descriptive statistics and correlation for Southern and West Africa

Descriptive	SOUTHERN AFRICA										
	REC	PD	FD	GDPC	UBZ	CCR	GES	PSA	VAA	RQL	RLW
Mean	44.186	46.327	49.199	4486.985	45.510	-0.069	-0.067	0.109	0.110	-0.086	-0.108
Median	33.000	44.463	27.853	3442.287	41.777	0.125	0.279	0.024	0.513	0.373	0.063
Maximum	87.350	126.452	142.422	10892.54	70.877	1.244	1.160	1.175	1.140	1.196	1.041
Minimum	8.703	6.440	-48.05	428.205	26.058	-1.425	-1.553	-1.58	-1.674	-2.201	-1.87
Std. Dev.	30.712	25.351	44.804	3196.931	13.506	0.758	0.791	0.794	0.821	0.959	0.867
Skewness	0.263	0.873	0.536	-0.058	0.341	-0.388	-0.444	-0.199	-0.859	-0.754	-0.548
Kurtosis	1.294	3.971	1.984	1.527	1.672	1.996	1.789	1.742	2.273	2.317	2.112
Jarque-Bera	16.595	20.829	11.378	11.361	11.609	8.387	11.745	9.070	18.120	14.297	10.364
Probability	0.000	0.000	0.003	0.003	0.003	0.015	0.002	0.010	0.000	0.000	0.005
Correlation											
REC	1.000										
PD	0.323	1.000									
FD	-0.810	-0.082	1.000								
GDPC	-0.964	-0.347	0.725	1.000							
UBZ	-0.768	-0.607	0.564	0.744	1.000						
CCR	-0.736	-0.447	0.364	0.737	0.685	1.000					
GES	-0.897	-0.256	0.627	0.889	0.608	0.886	1.000				
PSA	-0.838	-0.211	0.599	0.795	0.608	0.859	0.915	1.000			
VAA	-0.601	-0.279	0.159	0.668	0.431	0.820	0.767	0.800	1.000		
RQL	-0.828	-0.362	0.549	0.834	0.644	0.922	0.933	0.938	0.809	1.000	
RLW	-0.787	-0.248	0.449	0.790	0.514	0.888	0.920	0.949	0.907	0.934	1.000
Descriptive	WEST AFRICA										
Mean	67.458	78.240	15.618	1095.332	41.787	-0.562	-0.772	-0.453	-0.339	-0.597	-0.634
Median	54.990	65.197	12.715	815.219	41.228	-0.682	-0.802	-0.264	-0.331	-0.560	-0.649
Maximum	92.156	434.907	73.192	3907.646	66.652	1.370	0.355	1.340	0.990	0.168	1.044

Minimum	2.824	7.276	-2.686	272.991	15.407	-1.581	-1.791	-2.438	-1.564	-1.657	-2.088
Std. Dev.	19.589	60.506	12.734	725.989	10.078	0.516	0.451	0.367	0.229	0.376	0.583
Skewness	-0.884	2.619	2.153	1.812	0.129	1.032	0.274	-0.42	0.234	-0.268	0.290
Kurtosis	2.835	12.328	8.315	6.174	3.106	4.060	2.362	2.468	2.198	2.331	2.456
J-BERA	42.744	1550.126	633.876	314.356	1.059	73.019	9.585	13.408	11.685	9.972	8.568
Probability	0.000	0.000	0.000	0.000	0.588	0.000	0.008	0.001	0.002	0.006	0.013
Correlation											
REC	1.000										
PD	0.116	1.000									
FD	-0.632	-0.144	1.000								
GDPC	-0.625	-0.139	0.708	1.000							
UBZ	-0.713	0.024	0.462	0.659	1.000						
CCR	-0.757	-0.057	0.678	0.542	0.395	1.000					
GES	-0.752	-0.132	0.504	0.567	0.455	0.801	1.000				
PSA	-0.648	-0.219	0.576	0.524	0.365	0.744	0.741	1.000			
VAA	-0.541	-0.031	0.356	0.167	0.269	0.606	0.568	0.613	1.000		
RQL	-0.617	-0.278	0.469	0.407	0.265	0.731	0.835	0.672	0.561	1.000	
RLW	-0.736	-0.201	0.599	0.482	0.446	0.849	0.836	0.813	0.730	0.796	1.000

Source: Authors Computation

Table 3 reveals evidence of cross-sectional dependency across nations in all four sub-regions. Hence, we reject the null hypothesis of no cross-sectional dependence and adopt a panel unit root that allows for cross-section dependence

Table 3: CSD Test

	Central Africa		Eastern Africa		Southern Africa		West Africa	
Variables	CD-test	p-value	CD-test	p-value	CD-test	p-value	CD-test	p-value
REC	6.312	0.000	4.682	0.000	11.453	0.000	16.686	0.000
PD	40.632	0.000	8.393	0.000	13.311	0.000	25.489	0.000
FD	7.261	0.000	6.453	0.000	4.381	0.000	10.234	0.000
GDPC	38.573	0.000	45.654	0.000	50.121	0.000	68.231	0.000
UBZ	8.522	0.000	31.334	0.000	8.222	0.000	14.235	0.000
CCR	5.325	0.000	9.324	0.000	7.221	0.000	5.466	0.000
GES	6.336	0.000	8.987	0.000	4.651	0.000	4.669	0.000
PSA	8.445	0.000	7.321	0.000	5.822	0.000	7.234	0.000
VAA	9.220	0.000	6.883	0.000	6.114	0.000	5.609	0.000
RQL	5.447	0.000	6.745	0.000	7.129	0.000	4.338	0.000
RLW	6.211	0.000	8.324	0.000	5.545	0.000	6.470	0.000

Source: Authors Computation

We tested for the stationarity properties of the data by adopting the unit root test, which helps to avoid spurious regressions. Hence, we employed the Pesaran Panel unit Root Test with cross-sectional and first difference means (CIPS). The results of the unit root show that all the variables, irrespective of the region, are not stationary at level but become stationary when differenced once.

Table 4: Panel Unit Root (CIPS)

	Central Africa		East Africa		Southern Africa		West Africa	
	CIPS							
Var	level	First Diff	level	First Diff	Level	First Diff	level	First Diff
REC	-1.701	-4.339	-1.248	-3.024	-2.051	-4.432	-1.865	-3.719
PD	-2.173	-5.153	-1.507	-4.089	-0.934	-4.152	-1.584	-4.714
FD	-1.949	-4.608	-1.203	-3.538	-0.855	-4.507	-2.155	-4.679
GDPC	-1.328	-3.598	-0.945	-4.059	-1.847	-3.943	-1.195	-3.368
UBZ	1.798	-4.987	-0.897	-5.965	-0.589	-0.476	-1.485	-4.132
CCR	-2.137	-5.148	-1.439	-4.73	-2.209	-4.307	-1.793	-4.385
GES	-2.074	-5.331	-2.000	-4.841	-1.968	-4.773	-2.114	-4.809
PSA	-1.456	-4.639	-1.556	-4.81	-1.506	-3.816	-2.031	-4.497
VAA	-1.561	-4.714	-2.128	-5.905	-2.083	-5.624	-2.013	-5.013
RQL	-2.289	-5.17	-2.085	-5.184	-1.869	-4.742	-2.088	-5.047
RLW	-2.049	-5.808	-1.507	-4.992	-1.833	-4.151	-1.591	-4.589
5% critical value		-2.33						

Source: Authors Computation

Table 5: Pedroni Cointegration Test

Test Stats.	Central Africa	East Africa	Southern Africa	West Africa
Panel V	0.390	4.071	3.235	9.035
Panel RHO	0.012	0.194	0.903	0.659
Panel T	-4.048	-3.424	-2.957	-2.376
Panel ADF	-2.085	-5.423	0.112	-2.592
Group RHO	0.783	-3.114	-3.435	1.290
Group T	-2.001	-1.375	-3.523	-3.287
Group ADF	-3.115	-3.453	0.096	-2.149

Source: Authors Computation

To test for the equilibrium long-run relationship among our variables, we first implemented the Pedroni cointegration approach, which is appropriate to use in a balanced panel data set, as is the case of our data set. Table 5 revealed that the null hypothesis of no cointegration is rejected at 5% and 1% significant levels in all four (4) subsamples of SSA. These results are because the number of test statistics in absolute terms greater than 2 (by the rule of thumb) is more than those lower than 2 in each subsample. For instance, in Central Africa, four (4) statistics out of seven are greater than 2 in absolute terms (that includes Panel T, Panel ADF, Group T, and Group ADF). In East and Southern Africa, the similar outcome of four statistics out of seven is also greater than 2, while in West Africa, five statistics out of seven are greater than 2 in absolute terms. This finding implies that a long-run equilibrium relationship exists between dependent and independent variables in all four regions. Further cointegration analysis was implemented using Westerlund's (2007) error correction to substantiate the result[1]

[1] In order to account for the presence of cross-sectional dependence in the variables as well as the integrating qualities of the variables, an error-correction based algorithm was employed for the cointegration test, as described by Westerlund (2007). Appendix 2 reports this output. Two of the statistics, Gt and Ga, look for evidence of cointegration inside a single cross-sectional unit (in this case, a country), while the other two, Pt and Pa, look for evidence of cointegration throughout the entire panel. For both the full panel and the individual cross-sections, the P-values indicate that the absence of cointegration should be rejected.

4.2. Main Results

We present the output (see Appendix 3) of the Feasible generalized least squares (FGLS) technique for a sample of 29 countries in SSA by revealing the major findings on whether public debt individually enhances REC or if its interaction with governance quality drives or hinders its effect on energy consumption. The analysis contains columns [1]-[6] of the models with the six broad indicators of governance quality variables together with their interactions with public debt. The coefficient of GDPC is positive and significant on REC at a 1% significance level in all the models. Thus, REC in Sub-Saharan Africa is driven by economic activity. Analogously, economic expansion encourages the use of renewable energy. The plausibility of this conclusion is inherent in the fact that economic expansion might push people to use fewer conventional energy sources that hurt the environment and are damaging to health and to convert to more efficient sustainable energy consumption patterns. This research output is in tandem with the empirical documentation of Khuong et al. (2019); Mukhtarov et al. (2020); Gozgor et al. (2020); and Oluoch et al. (2021), who highlighted the criticality of economic expansion on the consumption of renewable energy. The coefficient of FD exhibits a negative and significant influence on REC at a 1% significance level in all the model spec [1]-[6]. These findings show that FD has a detrimental effect on REC in Sub-Saharan Africa, all things being equal. This outcome supports the works of Saibu and Omoju (2016), Ankrah and Lin (2020), and Kwakwa (2020) but is contradicted by the outcomes of Anton and Nucu (2019), Asongu and Odhiambo (2020), Raza et al. (2020), Qamruzzaman and Jianguo (2020), Khan et al. (2020), Dimnwobiet al. (2022a), Dimnwobi et al. (2022c) and Somoyeet al. (2022) who established that financial advancement enhances REC. The negative impact of FD-REC linkage could be attributed to capital-intensive renewable projects being viewed as dangerous by most financial institutions in SSA, who consequently demand exorbitant interest rates on loans for such projects. This practice undermines the development of renewable energy sources by making it more difficult for developers to embark on such projects (Ankrah & Lin, 2020). Another factor is the form and focus of the SSA's financial sector, as it appears that most financial institutions operate to provide personal or individual services. For instance, project finance is less common among regional banks than consumer or retail banking (Ankrah & Lin, 2020).

Urbanization increases employment chances. With more employment choices and income growth, people will use more sustainable energy sources (Li & Haneklaus, 2022). However, from the study, the parameter estimate for urbanization (UBZ) is negative and statistically significant at a 5% level across the six-model specification supporting the outcome of Baye et al. (2020,) who obtained similar outcomes for 32 SSA nations between 1990 and 2015 while contradicting Bayale et al. (2021) Baye et al. (2021) and Akintande et al. (2020). The result may be explained by rising urbanization and increasing energy demand and the preference of SSA governments for fossil-based energy sources over renewable energy sources to meet these demands. Also, public debt (PD) generates a positive coefficient at a 1% significance level, implying that PD exerts a direct impact on rec across (1) to (6) and varies across the models (between 0.169 -0.188). Drawing from specs 2 and 4, a unit rise in the size of PD in SSA raises REC by 0.188% and 0.169%, respectively. This outcome shows the criticality of public debt in stimulating the utilization of renewable in SSA. This result is consistent with the Keynesian model, which contends that efficient use of public debt can increase an economy's capacity for economic expansion and infrastructural development. Our findings on the effectiveness of debt in increasing the utilization of renewable energy are consistent with Przychodzen and Przychodzen (2019) and Florea et al. (2021) for 27 transition economies and 11 European nations while disagreeing with Hashemizadeh et al. (2021) and Wang et al. (2020) for 20 emerging economies and BRICS, respectively.

Considering the role of governance quality (control of corruption, government effectiveness index, voice and accountability, political stability and absence of violence, regulatory quality index, and the rule of law index) in SSA, which is the central contribution of this study, we investigated the interacting effect of governance quality and public borrowing (PD) on REC. In particular, (1) to [6] consist of control of corruption (CCR), government effectiveness index (GE), voice and accountability (VAA), political stability and absence of violence (PSA), regulatory quality index (RQL), and the rule of law index (RLW), respectively which represent six governance indicators. Regarding parameter estimates, CCR, GES, VAA, PSA, RQL, and RLW impact REC negatively and significantly at a 5% significance level in SSA. This negative influence still holds even when governance quality variables interacted with public debt in models (1)-(6), respectively. These findings imply that the governance indicators negatively and significantly impact REC in SSA. This result is not unexpected given that SSA has a history of weak governance, including inadequate property rights protection, lax contract enforcement, widespread corruption, an unpredictable political climate, and poor regulatory framework and accountability (Acheampong et al., 2021). The effectiveness of SSA's governance infrastructure will determine if they achieve their goal of adopting sustainable and clean energy by 2030

SSA has seen the failure of several energy projects due to ineffective governance. For example, Ikejemba et al. (2017) investigated the causes of the collapse of 29 renewable energy projects in ten SSA nations, and one of the primary reasons for these projects' failure was less effective governance. Ineffective governance can dissuade private investors from engaging in clean energy. As a result, an effective governance mechanism is required to protect sustainable clean energy in SSA and make sustainable energy projects and initiatives viable. This study supports the outcome of Acheampong et al. (2022) and Acheampong (2023), who reported that SSA has been ineffective in eliminating energy poverty and boosting the utilization of clean cooking fuels, respectively. Answering the question "Does governance quality crowd out or moderate the incremental effect of public borrowing on REC in Sub-Saharan Africa" led us to account for the overall effect of using governance quality indicators to influence public debt to enhance REC in SSA. Models 1 to 6 indicate positive unconditional impacts of public debt and negative marginal effects from the interaction of the six governance indicators with PD, all of which are statistically significant at the 1% and 5% levels of significance, respectively in Columns [1] to [6]. By implication, the positive effect of public debt on REC in SSA is dampened by the level of governance quality, given that the unconditional and marginal effects of public debt led to negative synergy via the interaction terms. Furthermore, the findings show that governance (irrespective of the indicator employed) and public debt seem to influence REC differently and not synergistically

We employed the Prais-Winsten regression model with panel-corrected standard errors (PCSE) for robustness checks and to observe the consistency of the results of the FGLS. The results are presented in the right-hand side columns 1 to 6 with the labels PCSE 1 to PCSE 6. The coefficient of GDPC and PD exhibit a positive and significant impact on REC in SSA across the six models at a 1% significance level, respectively, which is consistent with the outcome of the FGLS result. Also, the output of FD exerts a negative and significant influence on rec across specs [1] to [6], which also tallies with the FGLS output at a 5% significant level. These findings imply that PD and GDPC drive REC while FD undermines REC in SSA. The negative effect of FD-REC linkage could also be attributed to the less-developed state of the financial sector prevalent in the selected nations. The coefficients of UBZ, on the other hand, yield a negative and significant influence on REC in columns 1, 2, and 5 but exert a positive and significant impact on REC in models 3, 4, and 6. This finding means that UBZ enhances REC in some models and retards the use of REC in some other models. Accounting for the role of governance in SSA, we also examine the interacting impact of governance quality and public borrowing (PD) on REC using PCSE. On the parameter estimates, control of corruption, government effectiveness, voice and accountability, regulatory quality, and the rule of law impact negatively and significantly on REC, while political stability and absence of violence exert a positive and significant influence on REC at a 5% significance level in SSA. However, when governance quality indicators interacted with public debt using the PCSE regression technique, all the interacting models [1] to [6] indicate positive unconditional effects of public debt and a negative marginal effect, respectively, from the interaction of the six governance indicators with public debt, all of which are statistically significant at the 1% and 5% levels of significance, respectively in Columns [1] to [6]. This result is also consistent with the findings from the FGLS result.

Table 6: Sub-sample Result (Central and West Africa) using AMG

	CENTRAL AFRICA						WEST AFRICA					
VARIABLES	AMG-1	AMG-2	AMG-3	AMG-4	AMG-5	AMG-6	AMG-1	AMG-2	AMG-3	AMG-4	AMG-5	AMG-6
GDPC	0.325**	0.745**	0.053**	0.027**	0.535**	1.446**	1.329**	2.388*	2.486**	1.901***	0.071**	0.751**
	(0.597)	(0.242)	(0.368)	(0.506)	(0.334)	(0.728)	(0.696)	(1.332)	(0.689)	(0.351)	(0.198)	(0.527)
	[2.125]	[2.600]	[2.039]	[2.018]	[2.229]	[2.530]	[2.784]	[1.792]	[2.472]	[5.407]	[-2.060]	[2.292]
FD	1.451***	1.487***	1.460***	1.481***	1.267***	1.218***	0.389**	0.009**	0.596**	0.377**	0.566**	0.123**
	(0.328)	(0.517)	(0.372)	(0.391)	(0.295)	(0.425)	(0.273)	(0.319)	(0.233)	(0.157)	(0.286)	(0.219)
	[4.427]	[2.876]	[3.921]	[3.783]	[4.299]	[2.865]	[2.424]	[0.027]	[2.563]	[2.400]	[1.982]	[2.561]
UBZ	-1.814**	-1.737**	-1.891***	-2.576**	-2.792*	-1.874*	-4.938**	-4.797**	-6.565*	-8.316***	-5.336***	-6.416***
	(0.753)	(0.182)	(0.429)	(0.160)	(0.710)	(0.493)	(0.342)	(0.122)	(0.806)	(2.588)	(1.822)	(2.008)
	[-2.834]	[-2.655]	[-3.362]	[-2.018]	[-1.682]	[-1.664]	[-2.478]	[-2.536]	[-1.725]	[-3.213]	[-2.929]	[-3.195]
PD	-1.604**	-0.802**	-0.874**	-0.143**	-1.092**	-1.022**	-0.399**	-0.650**	-0.218**	-0.367*	-0.918**	-0.764**
	(0.199)	(0.990)	(0.824)	(0.068)	(1.079)	(1.042)	(0.223)	(0.458)	(0.275)	(0.200)	(0.606)	(0.488)
	[-2.337]	[-2.810]	[-2.060]	[-2.110]	[-2.012]	[-2.981]	[-2.792]	[-2.419]	[-2.792]	[-1.835]	[-2.515]	[-2.564]
CCR	2.085**						-2.685***					
	(0.769)						(1.002)					
	[2.179]						[-2.679]					
PDCCR	-1.072**						1.240**					
	(0.882)						(0.509)					
	[-2.215]						[2.436]					
GES		0.255**						-1.682*				
		(0.685)						(0.024)				
		[2.095]						[-1.642]				
PDGES		-0.304**						0.965*				
		(0.689)						(0.547)				
		[-2.180]						[1.765]				
VAA			0.971**						2.252*			
			(0.180)						(1.396)			
			[2.445]						[1.613]			
PDVAA			-0.832**						-1.253*			
			(0.673)						(0.731)			
			[-2.236]						[-1.715]			
PSA				0.435**						0.390**		
				(0.430)						(0.200)		
				[2.012]						[2.487]		
PDPSA				-0.315***						-0.201**		
				(0.112)						(0.409)		

				[-2.815]						[-2.491]		
RQL					1.549**						2.877*	
					(0.511)						(0.776)	
					[2.025]						[1.620]	
PDRQL					-0.796**						-1.500*	
					(0.814)						(0.906)	
					[-2.977]						[-1.656]	
RLW						1.485**						2.884*
						(0.149)						(1.563)
						[2.564]						[1.845]
PDRLW						-0.689***						-1.659**
						(0.185)						(0.833)
						[-3.731]						[-1.992]
Constant	52.918*	47.586**	35.709	37.731*	47.568*	53.732	10.246**	2.438	6.361*	9.758*	13.579***	8.917***
	(31.860)	(22.143)	(22.453)	(20.666)	(25.464)	(33.016)	(4.716)	(3.171)	(3.591)	(5.398)	(3.565)	(3.087)
	[1.661]	[2.149]	[1.590]	[1.826]	[1.868]	[1.627]	[2.172]	[0.769]	[1.772]	[1.808]	[3.809]	[2.888]
Observations	125	125	125	125	125	125	325	325	325	325	325	325
Number of id	5	5	5	5	5	5	13	13	13	13	13	13

*** $p<0.01$ indicates significance at 1% level

Table 7: Sub-sample Result (East and Southern Africa) using AMG

	EAST AFRICA						SOUTHERN AFRICA					
VARIABLES	AMG-1	AMG-2	AMG-3	AMG-4	AMG-5	AMG-6	AMG-1	AMG-2	AMG-3	AMG-4	AMG-5	AMG-6
GDPC	1.101**	0.679**	2.298**	1.350**	1.050**	1.807**	5.801***	6.883***	5.469*	7.236***	7.988***	6.008***
	(0.166)	(0.170)	(0.773)	(0.112)	(0.828)	(0.620)	(1.028)	(1.968)	(2.857)	(2.509)	(2.467)	(1.680)
	[2.272]	[2.214]	[2.609]	[2.480]	[2.574]	[2.499]	[5.643]	[3.498]	[1.914]	[2.885]	[3.238]	[3.577]
FD	-1.029**	-0.733**	-1.397**	- 1.475*	-1.304**	-2.095***	-0.390**	-0.627***	-0.360**	-0.435**	-0.396**	-0.330*
	(0.286)	(0.121)	(0.308)	(0.113)	(0.125)	(0.656)	(0.162)	(0.221)	(0.219)	(0.434)	(0.611)	(0.172)
	[-2.161]	[-2.016]	[-2.296]	[-1.814]	[-2.581]	[-3.192]	[-2.398]	[-2.832]	[-1.642]	[-2.002]	[-2.649]	[-1.915]
UBZ	0.31**	0.232**	0.977**	0.461**	1.249**	3.578**	-4.715**	-4.126**	-1.049**	-5.596**	-5.075**	4.638**
	(0.721)	(1.456)	(1.411)	(1.266)	(1.351)	(0.491)	(0.674)	(0.291)	(0.658)	(0.971)	(0.219)	(0.733)
	[2.430]	[2.159]	[2.693]	[2.364]	[2.925]	[2.400]	[-2.707]	[-2.780]	[-2.185]	[-2.803]	[-2.617]	[2.295]
PD	0.011**	0.356**	0.226**	0.307**	1.025**	0.583**	0.134***	0.604**	0.388**	0.160**	0.394**	0.369**
	(0.553)	(0.443)	(0.093)	(0.393)	(0.500)	(0.181)	(0.029)	(0.638)	(0.035)	(0.468)	(0.345)	(0.436)
	[2.001]	[2.803]	[2.419]	[2.781]	[2.053]	[2.493]	[4.661]	[2.947]	[2.375]	[2.341]	[2.142]	[2.846]
CCR	0.188**						0.292**					
	(1.266)						(0.762)					
	[2.148]						[2.384]					
PDCCR	-0.024**						-0.019**					
	(0.679)						(0.533)					
	[-2.035]						[2.017]					
GES		2.736*						2.042***				
		(1.401)						(0.389)				
		[1.953]						[5.249]				
PDGES		-1.383**						-1.159**				
		(0.688)						(0.579)				
		[2.011]						[-2.000]				
VAA			0.303**						1.790***			
			(1.244)						(0.291)			
			[2.243]						[6.149]			
PDVAA			-0.185**						-0.403**			
			(0.640)						(1.254)			
			[-2.290]						[2.321]			
PSA				0.248**						0.651**		
				(0.306)						(1.226)		
				[0.809]						[2.531]		

PDPSA				0.193**						-0.358**		
				(0.097)						(0.788)		
				[1.990]						[-2.455]		
RQL					3.440***						0.074**	
					(1.248)						(1.029)	
					[2.756]						[0.072]	
PDRQL					-1.747**						-0.204**	
					(0.727)						(0.692)	
					[-2.404]						[-2.295]	
RLW						2.572**						1.482*
						(0.111)						(0.770)
						[2.827]						[1.924]
PDRLW						-1.150**						-0.089**
						(1.650)						(0.088)
						[-2.697]						[2.013]
Constant	-0.517	-15.236	-9.588	-7.389*	-3.039	-8.976	-4.927	-6.773	-4.827	-5.455	-8.481	-8.072
	(1.408)	(15.395)	(16.941)	(4.373)	(3.471)	(18.853)	(7.300)	(8.800)	(10.160)	(4.928)	(7.204)	(8.560)
	[-0.367]	[-0.990]	[-0.566]	[-1.690]	[-0.876]	[-0.476]	[-0.675]	[-0.770]	[-0.475]	[-1.107]	[-1.177]	[-0.943]
Observations	150	150	150	150	150	150	125	125	125	125	125	125
Number of id	6	6	6	6	6	6	5	5	5	5	5	5

*** $p<0.01$ indicates significance at 1% level

We adopt the Augmented mean group (AMG) to analyze the role of governance quality on the public debt-REC relationship. A total of four (4) sub-regions were used, which include Central, West, East, and Southern Africa. The results for Central and West Africa are presented in Table 6, while those of East and Southern Africa are in Table 7. In the case of Central Africa, the AMG result reveal that GDPC and FD exhibit a positive and significant impact on REC across the models. This finding implies that economic growth and financial development drive REC in Central Africa, consistent with Mukhtarov et al. (2020); Gozgor et al. (2020); Zhao et al. (20,20),and Oluoch et al. (2021), who documented that economic growth promotes REC and Asongu and Odhiambo (2020); Qamruzzaman and Jianguo (2020) Khan et al., (2020) and Dimnwobi et al., (2022a), who reported that financial advancement promotes REC. The coefficients of UBZ and PD, on the contrary, revealed a negative and significant influence on REC at a 5% significance level, respectively. It implies that borrowing and urbanization have a detrimental effect on REC in the Central African region. This finding is in tandem with the findings of Wang et al. (2020), Hashemizadeh et al. (2021), and Jianhua (2022), who validated a negative linkage between government debt and REC.

By implication, a higher level of public borrowing may lead to less public investment in the renewable energy sector, resulting in a decline in the utilization of renewable energy. Examining the linear effect of governance quality and public borrowing (PD) on REC in Central Africa, we observed that the coefficients of CCR, GE, VAA, PSA, RQL, and RLW impact positively and significantly on REC at a 5% significance level in CA. This positive influence did not hold when governance quality indicators interacted with public debt in models (1)-(6), respectively. Accordingly, specs [1] to [6] show negative unconditional impact of PD on REC and also negative marginal impacts, respectively from the interaction of the governance variables with PD, all of which are statistically significant at the 5% significance level, respectively in Columns [1] to [6]. By implication, the negative effect of public debt on REC in CA is equally supported by the level of governance quality, given that the unconditional and marginal effects of public debt led to further negative synergy via the interaction terms. Hence, the findings indicate that governance (irrespective of the indicator employed) and public debt seems to have the same influence onREC and can work together to depress REC in the Central African region.

For the case of the West African region, the coefficients of GDP and FD are positive and statistically relevant on REC at a 5% significance level in all the models [1]–[6]. This result implies that any unit rise in GDPC and FD will enhance the use of REC in West African states. Contrary to this, UBZ and PD yield negative and statistically significant impacts on REC in all the models at a 5% significant level in the region. The unconditional impact of PD on REC is negative, but when interacting with governance indicators except for columns [1] and [2], where the marginal impact of PD is positive, others are negative. This finding implies that for specs [1] and [2], PD and governance variables are substitutes and not complimentary, while specs [3] to [6] reveal a complementary relationship between governance indicators and PD in influencing REC in West Africa

For the East African region, GDPC, UBZ, and PD positively and significantly impact the REC in all the columns, while FD yields a negative and significant influence on REC. This finding implies that a unit rise in GDPC, UBZ, and public debt will drive renewable energy use at a 5% significance level, whereas a unit increase in FD deteriorates utilization of REC in East Africa. For instance, the coefficients of GDPC, UBZ, and PD are all positive and significant. Also, a unit rise in FD will bring about decreases in REC for the region. As for the marginal effect of PD on REC due to interaction with institutional indicators, we observed a negative and significant marginal impact of PD on REC in all the specs except spec [4], where the PSA indicator was applied. These results also show that for most of the models, governance and public debt have different effects on renewable energy consumption. Finally, in the Southern African sub-sample, GDPC and PD exhibit positive and significant influence on REC at the 1% and 5% significance levels, respectively. These findings attune with the findings of Mukhtarov et al. (2020),Gozgor et al. (2020,) and Oluoch et al. (2021), who documented that economic growth drives REC, as well as Przychodzen and Przychodzen (2019) and Florea et al. (2021) who established a positive linkage between debt and REC. The coefficients of FD and UBZ exert a negative and significant influence on REC at a 5% significance level in all the model spec [1]-[6]. These results indicate that FD and UBZ significantly reduce REC in the Southern African region, ceteris paribus. On the role of governance quality in stimulating PD to enhance REC, we find that CCR, GE, VAA, PSA RQL, and RLW positively impact REC at a 5% significance level in Southern Africa. This positive influence could not hold when governance quality variables interacted with public debt in models (1)-(6), respectively. For the interaction variables, models[1]-[6] show positive unconditional impacts of public debt, and negative marginal effects from the interaction of the six governance indicators with PD, all of which are statistically significant at the 5% level s of significance, respectively in Columns [1] to [6]. By implication, the positive effect of public debt on REC in Southern African nations is deteriorated by the level of governance quality, given that the unconditional and marginal effects of public debt led to negative synergy via the interaction terms. Furthermore, the findings show that governance (irrespective of the indicator employed) and public debt affect REC differently and not synergistically.

5. Policy Insights and Conclusion

The findings indicate that public debt has a direct positive impact on REC in SSA. Therefore, SSA economies should increase their investment in renewable energy through public debt financing and other special borrowing arrangements to finance renewable energy projects to improve access to clean energy sources and help meet energy demand. For this to succeed, there is a need for inventiveness in handling the existing fiscal space to guarantee macroeconomic stability amid the hazy global economic picture following the uncertain COVID-19 economic rebound, the Russian-Ukraine conflict, looming global recession and the precarious situation of Sub-Saharan African (SSA) economies. Policymakers should prioritise decisions about public spending that are free of corruption to minimize fiscal distress, which could obstruct financing for the region’s energy sector. Likewise, policymakers should be motivated by their potential to enhance fiscal stimulus and pay for budget deficits. However, given the negative synergy between public debt and governance quality, public debt investments must be targeted toward renewable energy projects that are transparently and efficiently managed. Also, as the estimation results suggest, the weak governance infrastructure in SSA has hindered the adoption and usage of renewable energy. Consequently, the region should improve governance quality by ensuring adequate property rights protection, enforcing contracts, reducing corruption, providing a predictable political climate, and enhancing regulatory framework and accountability to encourage investment in renewable energy. These improvements would create an enabling environment for renewable energy adoption and usage.

Furthermore, our findings indicate that financial development has a detrimental effect on REC. As a result, increasing investment in financial development is crucial for promoting renewable energy. Governments in the region can work with financial institutions to develop innovative financing mechanisms that promote renewable energy projects. Specifically, more efforts should be devoted to promoting private sector investment in renewable energy by offering incentives, subsidies, and other forms of support. This approach would enhance REC and foster sustainable economic growth and development.

Additionally, the result suggests that rising urbanization increases energy demand in SSA. Authorities in Sub-Saharan Africa should promote the use of renewable energy sources in urban areas, which could help to reduce the demand for fossil fuels and mitigate the negative impact of urbanization on REC. This approach emphasizes the need to promote energy efficiency by encouraging the use of energy-saving appliances, implementing building codes that require energy-efficient buildings, and promoting public awareness campaigns on energy conservation through targeted media campaigns, workshops, and community outreach programs. Another policy to drive clean energy rests on deepening regional cooperation, with the African Energy Commission at the heart of the efforts. Hence, the necessity to intensify collaboration in the region to pool resources and expertise in renewable energy projects is paramount. Regional cooperation can promote the development and sharing of renewable energy technologies, lower costs, encourage investment, and jointly address common challenges such as infrastructure and financing.

From the research findings of the four sub-panels within the SSA region, the following policy recommendations are highlighted for each region: for Central Africa, in addition to exploring other financing options, such as green bonds, Central African countries could also consider adopting debt-for-climate swaps. These involve exchanging a portion of a country’s debt for investments in climate change mitigation and adaptation projects, including renewable energy. For example, the Democratic Republic of Congo has already implemented such a scheme, exchanging a portion of its debt with Italy for funding for renewable energy projects. To attract private investment in the renewable energy sector, policymakers in West Africa should consider bolstering tax incentives and subsidies to renewable energy companies. They should also consider establishing favourable regulatory frameworks and providing technical assistance to renewable energy project developers. In addition to improving governance quality, West African governments should prioritize regional cooperation to enhance renewable energy adoption and implementation. This approach should involve developing cross-border energy infrastructure, sharing best practices, and leveraging regional organizations such as the Economic Community of West African States (ECOWAS). East African governments should prioritize project selection and management to ensure that public debt is used effectively to finance renewable energy projects. They could establish clear project selection criteria based on economic viability, environmental sustainability, and social impact and monitor projects closely to ensure they are implemented efficiently. This approach could involve establishing independent regulatory bodies, developing clear rules and guidelines for renewable energy project development and operation, and promoting transparency and accountability in public financial management. Lastly, Southern African countries could consider developing innovative financing mechanisms such as green bonds, climate funds, and crowd-funding. They could also establish public-private partnerships to leverage private sector expertise and funding in renewable energy project development. Southern African countries should prioritize institutional and capacity development to improve governance quality.

In conclusion, this study examined the role of governance quality in the relationship between public debt and REC in Sub-Saharan Africa. The findings indicate that public debt positively affects REC in the region. However, the positive effect is dampened by the level of governance quality, as weak governance infrastructure impedes the utilization of renewable energy sources. The study further reveals that governance and public debt influence REC differently and not synergistically. To improve the fortunes of financing the SSA energy sector, countries in the region should prioritize transparency and accountability in their sectorial fiscal and financial management systems. Consideration should be given to establishing independent regulatory bodies to oversee the energy sector, promote investment and competition, and ensure that renewable energy projects are developed transparently and sustainably. Additionally, establishing regional renewable energy centres of excellence to share knowledge and expertise on sustainable energy financing, renewable energy development, and beyond remain essential for SSA.

However, some of the possible limitations of this study are that it uses aggregated public debt data to measure public debt, and future inquiries should consider disaggregating public debt into domestic and external debt. Detailed data will help inform decision-makers on the component of debt to prioritise. Secondly, owing to data unavailability, this study was limited to 29 SSA nations; further studies should expand to a larger panel of other nations. Lastly, aside from the variables employed in this study, other factors could influence REC; future studies should incorporate other REC drivers using various nations and timeframes.

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Appendix 1: The Study Sample (29 SSA Nations)

Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central Africa Republic, Chad, Comoros, Congo Republic, Cote d'Ivoire, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali, Mauritius, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Tanzania, Togo, Zimbabwe

Appendix 2: Westerlund (2007) bootstrap test

	Gt	Ga	Pt	Pa
Models	Value	Value	Value	Value
1. Central Africa	-2.403***	-12.608***	-13.639***	-6.953***
2. West Africa	-2.302***	-11.045***	-12.693***	-7.523***
3. Southern Africa	-0.464***	-0.689***	-0.151***	-0.717***
4. East Africa	-3.365***	-10.600***	-4.142***	-8.711***
Notes: *** p<0.01, ** p<0.05, * p<0.1; statistically significant indicates a rejection of the null hypothesis of no cointegration; Robust P-Values are from Bootstrap replications of the critical values				

Appendix 3: FGLS Results for the Full Sample

	'FULL SAMPLE						ROBUST CHECK: FULL SAMPLE					
VARIABLES	fgls-1	fgls-2	fgls-3	fgls-4	fgls-5	fgls-6	pcse-1	pcse-2	pcse-3	pcse-4	pcse-5	pcse-6
GDPC	0.358***	0.287***	0.365***	0.375***	0.349***	0.341***	0.507***	0.471***	0.574***	0.568***	0.574***	0.546***
	(0.060)	(0.066)	(0.062)	(0.065)	(0.067)	(0.064)	(0.080)	(0.086)	(0.085)	(0.086)	(0.090)	(0.087)
	[5.923]	[4.325]	[5.914]	[5.731]	[5.203]	[5.334]	[6.352]	[5.500]	[6.741]	[6.599]	[6.378]	[6.285]
FD	-0.136***	-0.152***	-0.157***	-0.184***	-0.168***	-0.161***	-0.022**	-0.036**	-0.042**	-0.079**	-0.076**	-0.052**
	(0.047)	(0.047)	(0.049)	(0.048)	(0.049)	(0.047)	(0.052)	(0.051)	(0.054)	(0.052)	(0.053)	(0.052)
	[-2.871]	[-3.257]	[-3.199]	[-3.871]	[-3.465]	[-3.425]	[-0.435]	[-0.703]	[-0.785]	[-1.515]	[-1.429]	[-0.983]
UBZ	-0.073**	-0.153**	-0.06**	-0.076**	-0.117**	-0.105***	-0.175**	-0.142**	0.250*	0.264**	-0.218**	0.216*
	(0.111)	(0.113)	(0.114)	(0.118)	(0.117)	(0.111)	(0.125)	(0.128)	(0.132)	(0.134)	(0.133)	(0.129)
	[-2.655]	[-2.356]	[-2.530]	[-2.642]	[-2.001]	[-2.948]	[1.398]	[1.109]	[1.904]	[1.969]	[1.644]	[1.672]
PD	0.178***	0.188***	0.170***	0.169***	0.172***	0.172***	0.132***	0.139***	0.141***	0.134***	0.115***	0.124***
	(0.024)	(0.025)	(0.021)	(0.023)	(0.025)	(0.025)	(0.035)	(0.039)	(0.028)	(0.030)	(0.034)	(0.036)
	[7.482]	[7.559]	[8.015]	[7.454]	[6.976]	[6.891]	[3.805]	[3.603]	[5.020]	[4.447]	[3.364]	[3.431]
CCR	-0.095**						-0.079**					
	(0.048)						(0.064)					
	[-1.971]						[-2.241]					
PDCCR	-0.003**						-0.057**					
	(0.028)						(0.039)					
	[-2.101]						[-2.455]					
GES		-0.125***						-0.094**				
		(0.047)						(0.064)				
		[-2.638]						[-2.469]				
PDGES		-0.014**						-0.040**				
		(0.026)						(0.037)				
		[2.541]						[-2.068]				
VAA			-0.045***						-0.035**			
			(0.046)						(0.054)			
			[-2.981]						[-2.646]			
PDVAA			-0.012**						-0.034**			
			(0.026)						(0.031)			
			[-2.456]						[-2.107]			
PSA				-0.008**						0.018**		
				(0.039)						(0.046)		
				[-2.206]						[2.391]		

PDPSA				-0.016**						-0.052*		
				(0.023)						(0.028)		
				[-2.688]						[-1.844]		
RQL					-0.050***						-0.042**	
					(0.053)						(0.064)	
					[-2.940]						[-2.648]	
PDRQL					-0.007**						-0.066*	
					(0.029)						(0.037)	
					[-2.224]						[-1.782]	
RLW						-0.059**						-0.012**
						(0.051)						(0.064)
						[-2.160]						[-2.181]
PDRLW						-0.006**						-0.056**
						(0.028)						(0.036)
						[-2.225]						[-2.550]
Constant	2.742***	2.638***	2.803***	2.899***	2.846***	2.790***	2.711***	2.647***	2.853***	2.874***	2.984***	2.839***
	(0.163)	(0.175)	(0.170)	(0.170)	(0.171)	(0.170)	(0.189)	(0.208)	(0.203)	(0.197)	(0.206)	(0.207)
	[16.848]	[15.064]	[16.524]	[17.040]	[16.633]	[16.428]	[14.313]	[12.728]	[14.018]	[14.622]	[14.459]	[13.693]
Observations	725	725	725	725	725	725	725	725	725	725	725	725
Number of id	29	29	29	29	29	29	29	29	29	29	29	29
R-square							0.337	0.33	0.313	0.312	0.309	0.319

Standard errors in brackets () t-statistics []

*** $p<0.01$ indicates significance at the 1% level