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Sustainability Burden or Boost? Examining the Effect of Public Debt on Renewable Energy Consumption in Sub-Saharan Africa

Forthcoming: Energy Sources, Part B: Economics, Planning, and Policy

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Abstract

Given that the development of renewable energy is regarded as a sustainable alternative to the realization of environmental quality, it is not surprising that the discussion of the sustainability of the world's energy sources continues to expand. While renewable energy has a negligible impact on environmental degradation, developing regions like sub-Saharan Africa (SSA) is restricted by the capital-intensive investment requirements of the burgeoning renewable energy market. To explore the significance of available funding sources on renewable energy development in the region, this study investigates the influence of public debt on renewable energy consumption (REC) in a panel of 29 SSA countries, in full and sub-regional categorizations. A combination of the instrumental variable generalized method of moment (IV-GMM) approach and the two-stage least squares estimator was applied to achieve the goal of the study. Overall, our findings indicate that public debt, carbon emission, financial development, and economic growth exert a negative and significant linkage with renewable energy, while urbanization has a positive and significant influence. Aware of the study findings, appropriate policy prescriptions are proposed to improve the debt-financed funding for the development of the renewable energy sector in SSA.

Keywords: Public Debt, Renewable Energy, Financial Development, Economic Growth, Carbon Emission

1. Introduction

The urgent need to address climate change has become increasingly undeniable, given the obvious identification of several global environmental threats (Przychodzen and Przychodzen, 2019). Many approaches have been advocated, including the development of pro-environmental technologies (Agyekum et al., 2021; Rahman and Alam, 2022), energy and water conservation (Hashemizadeh et al., 2021), and energy efficiency improvements (Dimnwobi et al., 2023). The generation and utilization of renewable energy also rank highly as a well-accepted solution to reduce carbon emissions (Kinab and Elkhoury, 2012). In this regard, environmental protectionists encourage the use of renewable energy rather than fossil energy sources to better fulfil the obligations of the sustainable development goals (Hashemizadeh et al., 2021; Kruger, 2022). Renewable energy consumption (REC) not only benefits the environment but also assists economies to lessen their reliance on foreign resources while boosting employment and general development outcomes (Asongu and Odhiambo, 2020; Dimnwobi et al., 2022a). A considerable amount of energy supply is incorporated into renewable energy, allowing it to improve the energy mix available and compensate for market fluctuations while also being environmentally conscious (Xu et al., 2019). Renewable energy accounted for roughly 19% of total global final energy consumption in 2015 (REN21, 2017), which the International Renewable Energy Agency projects to hit 60% or higher by 2050 (IRENA, 2018). As a result, expanding the various renewable energy sources is critical in the national and regional transition to a climate-friendly economy (Edziah et al., 2022; Kruger, 2022). It is equally worth noting that renewable energy is regarded as the sole climate-friendly and long-term solution capable of mitigating climate change and global warming (Hashemizadeh et al., 2021). Accordingly, it has brought energy sustainability and solutions to the forefront of various international debates.

Because of its comparatively sluggish growth regionally, Africa has portrayed a distinct and atypical dialogue on both global warming and energy transition (Dimnwobi et al., 2021). The region currently produces about 2% of the total global emissions, making it a relatively small contributor to global greenhouse gas (GHG) emissions, but by 2040, emissions are projected to rise to 3% (IEA, 2019). However, the potential of the region's renewable energy resources has been significantly underutilized in comparison to present and projected energy utilization (IEA, 2019). The region possesses the richest and most underutilized solar resources globally as it has installed only 5 gigawatts (GW) of solar photovoltaic (PV), accounting for less than 1% of installed capacity worldwide (IEA, 2019). However, given the falling cost of renewable technology across the region and the abundance of renewable sources, the region's solar expansion is anticipated to reach roughly 320 Gigawatts (GWs) in 2040, overtaking natural gas and hydropower to become the main source of electricity (AREI, 2019; IEA, 2019). The International Energy Agency (2019) also suggests that other renewable energy sources are increasingly being explored in sub-Saharan Africa (SSA), including geothermal energy in Kenya and wind energy in South Africa, Kenya, Ethiopia, and Senegal. According to the Africa Renewable Energy Initiative (AREI), it is crucial to continue harnessing renewable energy sources in the region because it boosts household access to electricity and supports the growth of sectors like industrial, agriculture, transportation, and micro, small, and medium-sized businesses. Therefore, to meet the region's predicted energy demand while reducing losses by around 10%, an increase in investment in Africa's power sector is critical (IEA, 2019).

Given the higher financial implication of renewable energy compared to traditional energy sources, access to financial resources is vital for countries to fund the development and deployment of renewable energy in their economies (Anton and Nucu, 2019; Dimnwobi et al., 2022b). In situations when domestic savings and foreign exchange earnings are in short supply to meet national developmental goals among others, governments borrow to supplement domestic financial capabilities and fund infrastructure deemed critical for rapid economic growth and development (Onafowora and Owoye, 2017). Since the mid-1970s, global public debt has risen steadily with nations borrowing to fund their fiscal gap (Onafowora and Owoye, 2017). Specifically, the SSA total public debt climbed from 26.7% of GDP in 2010 to 38.7% in 2015 before increasing to 48.2% in 2018. At the end of 2020, the region's debt has swelled to 57.8% (IMF, 2021), with the rapid public debt build-up largely facilitated by the Highly Indebted Poor Country (HIPC) debt interventions and Multilateral Debt Relief Initiatives (MDRI) (Mupunga and Ngundu, 2020). The fiscal space created by debt reduction programs, combined with better global liquidity and enhanced growth rates, has led to continued borrowing by SSA nations to fund infrastructure and development projects (IMF, 2015). The enhanced macroeconomic outcome, aided by increasing global commodity prices has similarly boosted their creditworthiness. Furthermore, additional borrowing options arose given the supportive liquidity circumstances in global capital markets, the expansion of domestic financial markets in various SSA nations, and the expanding lending activity of non-Paris Club nations (IMF, 2015). Following the COVID-19 outbreak, several African nations have begun a fresh round of borrowing to increase public investment and promote economic outcomes. Consequently, public debt, in addition to its conventional relevance in public sector economics literature, has recently been explored and utilized as a source of funding for environmental programs (Hashemizadeh et al., 2021).

Based on the foregoing background, the study proposes practical and effective measures for sustainable debt management to assist SSA and its sub-regions in adopting clean and modern energy sources through practical recommendations for policymakers. Hence, the main research questions addressed in this inquiry are: (i) What is the effect of public debt on REC in SSA? (ii) Does the effect of public debt on REC differ across SSA sub-regions? In answering these questions, this study extends the extant literature in five ways. First, as far as we know, this study represents the first effort in examining the implication of public debt on REC in the SSA region. The region's growing public debt and its impact on the SSA economy have been the subject of ongoing debate. However, several national governments across SSA continue to defend borrowing as necessary for filling infrastructure gaps and boosting development outcomes. In particular, it is touted as essential to address the energy poverty issue by prioritizing renewable energy investment as capable of energizing the regional economy to attain several sustainable development goals. However, question marks continue to trail the perceived long-term gains of public borrowings in the region vis-à-vis a mounting debt accumulation with a likely debt crisis on the horizon (Kemoe and Lartey 2021), vulnerability to macroeconomic shocks (Okafor et al., 2022) and implications for achieving the 2030 Global Development Agenda (Sani et al., 2019). Also, drawing inferences from studies conducted elsewhere is bound to be limited from a policy perspective given SSA's peculiar macroeconomic environment. Second, to offer a thorough insight, empirical assessments are done for four SSA regions (Central, East, South, and West) in comparison with the full SSA sample. Hence, the study offers robust empirical evidence not only for comparison but also for distinct regional policymaking in the sub-regions of SSA. Third, we applied the instrumental variable generalized method of moment (IVGMM) approach as the estimation technique for the full sample, while the two-stage least squares (2SLS) estimator was applied for the sub-regional analysis. These techniques deal with diverse econometric issues including potential endogeneity, error correlations, and reverse causality in macro data among others, making its findings more reliable and accurate. Fourth, we concentrate on SSA because the region's public borrowing has grown at an alarming rate and remains energy-poor despite having natural energy deposits. Lastly, practical and effective measures have been proposed to assist SSA and its sub-regions adopt clean and modern energy sources through sustainable debt management to attain most of the sustainable development goals by 2030.

Overall, this study aims to make a modest and valuable contribution to the existing literature on the relationship between public debt and renewable energy consumption in Sub-Saharan Africa. The contribution of this work relative to existing studies is premised on its special focus on the Sub-Saharan Africa region, which has unique characteristics and challenges in terms of renewable energy consumption and debt management. By examining this relationship in this context, the study provides more specific and relevant insights that can inform policy decisions in the region. Hence, the study will help policymakers and researchers better understand the impact of public debt on renewable energy adoption and implementation, which is essential for mitigating the adverse effects of climate change in the region in particular and achieving the SDGs in general. Following this, what remains of this study is divided as follows: The literature review is documented in section 2 while section 3 describes the methodology and data. Section 4 and 5 contains the main results and conclusion respectively

2. Literature Review

2.1 Theoretical underpinnings

There is no agreement in the literature (Florea et al. 2021; Hashemizadeh et al. 2021; Wang et al. 2020) about the impact of public debt (PBD) on economic outcomes, either theoretically or empirically. Different perspectives can be used to explain how public debt influences economic outcomes. For instance, classical economists generally adhered to the laissez-faire economic idea and considered a national debt to be a societal burden, upholding the notion of a balanced budget and opposing the idea of borrowing money to fund it. Likewise, the Ricardian viewpoint regards public debt to be comparable to future taxes hence implying the neutrality of debt to economic outcomes. Howbeit, the Keynesian view supports government borrowing. It argues that an increase in government expenditure through debt can stimulate economic outcomes by assuring efficient resource allocation, effective market regulation, and economic stabilization (Barik and Sahu, 2020). On the other hand, debt overhang theory avers that excessive borrowing results in high debt levels, debt traps, and economic slowdowns. The theory predicts that debt servicing costs may deter additional foreign and domestic investment if there is a chance that the public debt could eventually be higher than the nation's capacity to repay it (Yusuf et al., 2021). As noted by Krugman (1988), mounting public debt serves as a tax on future output while also reducing the motivation to save and invest. The theory specifically suggests the need to pay off debt limits the amount of money available for investments, hence, a mandatory liquidity cap on the debt would deter investment and slow economic progress (Yusuf et al., 2021).

2.2 Empirical review

On the empirical front, one of the primary arguments for promoting REC and development is that it is climate-friendly relative to non-renewable energy. Accordingly, this section presents a review of existing related studies and the review is paragraphed into four major strands. The first strand is focused on the implications of PBD on REC. The second strand examines the effect of financial development (FD) on REC. Third, a highlight of studies on economic growth (GDP) and REC while the last strand focuses on the implications of urbanization (URN) and REC. Table 1 documents the empirical literature surveyed.

2.2.1. Public debt and renewable debt nexus

Florea et al. (2021) applied the fully modified ordinary least squares (FMOLS) to assess the implications of PBD on REC in selected European Union emerging economies. The study established that PBD stimulates REC. Likewise, Przychodzen and Przychodzen (2019) assessed the factors influencing renewable energy generation in 27 transition economies from 1990 to 2014. The study identified that PBD, unemployment level and economic growth stimulate renewable energy generation. While the foregoing concludes that PBD promotes REC, some studies report otherwise. For instance, Hashemizadeh et al. (2021) assessed the implication of PBD on REC in selected emerging nations between 1990 and 2016 and discovered that REC is reduced by PBD. In a similar study of 23 Asian nations between 1990 and 2019, Jianhua (2022) discovered that rising PBD causes a drop in the REC. Wang et al. (2020) examined the interaction between REC and PBD on human development in Brazil, Russia, India, China, and South Africa (BRICS) nations between 1990 and 2016, and the study highlights, among other things, that a higher PBD level may result in less government investment in the renewable energy sector, resulting in lower REC. It is worth noting from the survey of literature on the nexus between public borrowing and REC that the subject matter is currently underexplored and no study (to our knowledge) has focused on SSA despite the region's increasing debt profile and energy poverty situation. The empirical narration above paints a mixed picture of how public debt would impact renewable energy. In this instance, we suggest that:

H_1. There is a significant relationship between public debt and REC in Sub-Saharan Africa

A robust financial sector has been hypothesized to drive clean energy development. Given this, several studies have shown that FD impacts REC; howbeit, the degree of this impact varies across two different schools of thought and this review tows that line. The first school of thought reported that FD stimulates REC. For instance, Omojolaibi (2016) assessed the role of FD on REC in Nigeria between 1980 and 2008 and discovered that FD is critical for Nigeria's renewable energy development. Between 1992 and 2013, Ji and Zhang (2019) used a vector autoregression (VAR) model to appraise the criticality of FD on China's REC. The study discovered that the development of the financial sector enhances the country's REC. In a similar study in India from 1971 to 2015, Eren et al. (2019) conclude that REC is stimulated by FD. Anton and Nucu (2019) sampled 28 EU nations to assess the effect of FD on REC and the study reported that FD is a significant REC driver. For selected SSA nations between 2004 and 2014, Asongu and Odhiambo (2020) utilized the Generalized Method of Moments (GMM) and discovered that REC is stimulated by FD. Raza et al. (2020) examined the nexus between FD and REC of 15 top renewable energy consumers between 1997 and 2017 and the study concludes that FD stimulates REC. Qamruzzaman and Jianguo (2020) reported the same outcome using data from selected nations cutting across diverse income groups. In another study, Khan et al. (2020) reported a positive connection between both variables for a group of 192 nations using Panel quantile regression. Likewise, Dimnwobi et al (2022a) obtained a similar outcome using data from Nigeria. On the other hand, the second school of thought reports that FD discourages REC. For instance, Saibu and Omoju (2016) discovered that FD reduces REC in Nigeria between 1981 and 2011. A similar outcome was reported in a recent study in Ghana by Ankrah and Lin (2020)

The level of income is seen as an inextricable factor in REC. Focusing on the nexus between GDP and REC in G7 nations, Sadorsky (2009) found that GDP is a critical driver of REC. In a similar study of China between 1980 and 2011, Lin et al. (2016) discovered that GDP stimulates REC. For the period 1995 to 2013, Khuong et al. (2019) appraised the predictors of renewable energy in the Association of South-East Asian Nations (ASEAN) and identified GDP and urbanization as major drivers. In Azerbaijan, Mukhtarov et al. (2020) utilized the autoregressive distributed lag (ARDL) technique and discovered that GDP stimulates REC. Premised on a dynamic system-GMM panel model, Chen (2018) found, among other things, that GDP promotes REC in China between 1996 and 2013. In a similar study in China, Zhao et al. (2020) utilized the FMOLS technique between 1980 and 2016 and revealed that GDP enhances REC. Gozgor et al. (2020) and Oluoch et al. (2021) obtained similar outcomes for OECD and SSA nations respectively. Conversely, some other studies reported that GDP is negatively related to REC. For instance, Ergun et al. (2019) assessed the factors that influence the use of renewable energy in 21 African nations and the authors discovered that while foreign direct investment is positively connected to REC, GDP and human development index are negatively linked to REC. Kwakwa (2020) obtained similar findings in a recent study in Ghana using the ARDL and FMOLS between 1971 and 2014.

In a similar vein, the literature has explored the connection between URN and REC with interesting findings. For instance, Malik et al (2014) assessed the implications of macroeconomic factors on REC in Pakistan over the period 1975 to 2012 and reported that URN, population, inflation, food production index, exchange rate, oil rent, industrialization, and livestock production index boosts REC. Similarly, Mehrara et al. (2015) looked into the factors that influence REC in Economic Cooperation Organization (ECO) nations from 1992 to 2011 and the study showed that URN, government effectiveness, human capital, and political instability are the major factors. Akintande et al. (2020) estimated the drivers of REC in Africa's five most populated countries between 1996 and 2016. The study identified urban population, population growth, electric power consumption, human capital, and energy use as the major drivers of Africa's REC. Baye et al. (2021) evaluated the factors driving REC in 32 SSA nations between 1990 and 2015 and found that URN stimulates SSA REC. Using the same scope, Baye et al (2020) found the opposite. Bayale et al. (2021) assessed the drivers of renewable energy generation in West African Economic and Monetary Union (WAEMU) nations from 1990 to 2017. The research discovered that URN, unemployment, and energy investment encourage renewable energy production while energy imports and carbon emissions undermine renewable energy production.

Table 1: Summary of literature

Author(s)	Study period	Nations	Methodology	Variables	Findings
			PBD-REC		
Przychodzen & Przychodzen (2019)	1990-2014	27 transition nations	Analysis of variance	GDP, unemployment, domestic credit, inflation (INF), foreign direct investment (FDI), REC, PBD, current account balance	PBD stimulates REC
Florea et al (2021)	1995-2015	11 EU nations	FMOLS	REC, PBD, GDP, budget surplus or deficit, trade openness (TO)	PBD stimulates REC
Hashemizadeh et al. (2021)	1990-2016	20 emerging economies	Driscoll-Kraay standard errors	REC, GDP, PBD, URN, TO	REC is reduced by PBD
Jianhua (2022)	1990-2019	23 Asian nation	ARDL	REC, GDP, PBD, CO2, financial globalization	PBD causes a drop in REC
Wang et al (2020)	1990-2016	BRICS	Driscoll-Kraay standard errors	REC, GDP, human development index (HDI), PBD, industrialization (IND)	PBD lowers REC
			FD-REC		
Omojolaibi (2016)	1980-2008	Nigeria	GMM	GDP, financial depth, commercial banks asset, credit provided by a commercial bank to the private sector, crude oil price, money supply, FDI, electricity generation from renewable sources	FD promotes REC
Saibu & Omoju (2016)	1981 to 2011	Nigeria	Vector Error Correction Model (VECM)	FD, REC, TO, GDP, fossil fuel	FD reduces REC
Ji & Zhang (2019)	1992-2013	China	VAR	GDP, REC, FDI, oil price, domestic credit provided by financial sector, market capitalization, CO2 emission	FD promotes REC
Eren et al. (2019)	1971–2015	India	Dynamic ordinary least	REC, GDP, FD	FD stimulates REC

Author(s)	Study period	Nations	Methodology	Variables	Findings
			squares (DOLS)		
Anton & Nucu (2019)	1990–2015	28 EU nations	Fixed effects model	FDI, REC, GDP, INF, domestic debt to private sector, stock market turnover	FD stimulates REC
Asongu & Odhi ambo (2020)	2004–2014	39 SSA nations	GMM	Inequality indicators, financial access, REC, regulatory quality, mobile phone penetration	REC is stimulated by FD
Raza et al. (2020)	1997–2017	15 top REC nations	Panel smooth transition regression (PSTR) model	FD, REC, IND, popul ation (POP)	FD stimulates REC
Ankrah& Lin (2020)	1980-2015	Ghana	VECM	FD, REC, TO, FDI, GDP, fossil fuel	FD reduces REC
Qamruzzaman &Jianguo (2020)	1990- 2017	114 economies	Non-linear ARDL, GMM	FD, REC, TO, FDI,	FD encourages REC
Khan et al. (2020)	1980-2018	192 economies	Quantile regression	FD, REC, TO, FDI, POP, labour force, CO_2	FD drives REC
Dimnwobi et al (2022a)	1981-2019	Nigeria	ARDL	FD, REC, GDP, FDI, inflation	FD drives REC
GDP-REC					
Sadorsky (2009)	1980- 2005	G7 nations	FMOLS, DOLS	REC, GDP, CO_2, oil price	GDP encourag es REC
Lin et al. (2016)	1980- 2011	China	VECM	FD, REC, GDP, FDI, TO, fossil fuel	GDP stimulates REC
Chen (2018)	1996–2013	China	GMM	REC, GDP, CO_2, URN, trade	GDP boosts REC
Khuong et al. (2019)	1995-2013	ASEAN nations	Impact matrix analysis	REC, GDP, URN, energy consumption	GDP promotes REC
Ergun et al. (2019)	1990-2013	21 African nations	Random-effects generalized least squares regres sion	REC, GDP, FDI, TO, HDI, democracy,	GDP discourages REC
Mukhtarov et al. (2020)	1993-2015	Azerbaijan	ARDL	FD, REC, GDP, INF	GDP promotes REC
Zhao et al. (2020)	1980–2016	China	FMOLS	FD, REC, GDP, TO	GDP boosts REC
Gozgor et al. (2020)	1970-2015	30 OECD nations	Panel correlated standard errors	REC, GDP, CO_2, oil price, globalization	GDP fosters REC

Author(s)	Study period	Nations	Methodology	Variables	Findings
Kwakwa (2020)	1971–2014	Ghana	ARDL, FMOLS	FD, REC, IND, INF	GDP discourages REC
Oluoch et al. (2021)	1998- 2014	23 SSA nations	ARDL	REC, GDP, CO2, corruption, education index, corruption, life expectancy	GDP fosters REC
URN-REC					
Malik et al (2014)	1975-2012	Pakistan	VECM	REC, URN, POP, IND, INF, exchange rate, food & livestock pro duction	URN boosts REC
Mehrara et al. (2015)	1992-2011	ECO nations	Weighted-ave rage least square (WALS) & Bay esian model a veraging (BMA)	GDP, FDI, POP, REC, governance indicators, capital formation, URN	URN drives REC
Akintande et al. (2020)	1996- 2016	5 African na tions	BMA	Governance indicators, GDP, POP, REC, URN, FDI, FD, school enrol lment, capital formation, gas price, energy use, electric power cons umption	URN drives REC
Baye et al (2020)	1990-2015	32 SSA nations	Corrected least squares dummy variable estimator (LSDVC)	REC, URN, TO, HDI, oil price, CO2, gove rnance indicators, economic globaliza tion, technology	URN lowers REC
Baye et al. (2021)	1990-2015	32 SSA nations	Driscoll-Kraay standard errors	GDP, REC, TO, POP, URN, oil price, resource rent	URN stimulates REC
Bayale et al (20 21)	1990-2017	8 West African nations	BMA, DOLS, FMOLS	GDP, URN, energy imports, CO2, unem ployment, energy in vestment, renewable energy production	URN encourages renewable energy production

Source: Authors' Computation

3. Methodology

3.1. Data

This study utilizes annual data on renewable energy consumption, public debt, GDP per capita, urbanization, financial development, and carbon emission. REC (% of overall final energy consumption) was chosen as the dependent variable following existing environmental sustainability literature (Asongu et al., 2019; Asongu and Odhiambo, 2020; Dimnwobi et al., 2022a). In line with Wang et al (2020) and Hashemizadeh et al (2021), we utilized public debt (% of GDP) to measure public debt. Following extant literature (Asongu et al., 2019; Ankrah and Lin, 2020; Kwakwa, 2020), financial development was captured using domestic credit to the private sector (% of GDP). The development of the financial sector facilitates the adoption of clean energy. Similarly, the real GDP per capita is utilized to account for the role of income on RE consumption levels. In line with recent studies (Baye et al., 2021; Oluoch et al., 2021; Zhang et al., 2021), carbon emission is included in the study to represent environmental awareness of global warming. Finally, urbanization is also included in the model in recognition of the critical role of urbanization on energy demand (Baye et al., 2021)

Except for data on public debt which was sourced from the Public Debt Database of the International Monetary Fund (IMF), all other data were obtained from the World Bank (World Development Indicators - WDI). The study covers 29 SSA nations (See Appendix 1) between 1990 and 2020. This periodicity was chosen in line with the data available for all the variables. All the variables utilized in this study as well as their description are documented in Table 2

Table 2: Variables Description

Variables	Measurement	Sources
Renewable energy consumption (REC)	% of total final energy consumption)	World Bank (WDI) Data
Public debt (PBD)	% of GDP	IMF Data
Financial development (FD)	Domestic credit to the private sector as a % of GDP	World Bank (WDI) Data
Gross Domestic Product Per Capita (GDPPC)	Constant 2010 US$	World Bank (WDI) Data
Urbanization (URN)	Urban population (% of total population)	World Bank (WDI) Data
Carbon dioxide emissions (CO_2)	Metric tons per capita	World Bank (WDI) Data

Source: Authors Computation

3.2. Model specification and Justification of estimation method

Based on the empirical and theoretical narrations domicile in Przychodzen and Przychodzen (2019); Barik and Sahu (2020); Florea et al. (2021) and Hashemizadeh et al. (2021), the present effort presents the Renewable energy consumption (REC) as a function of Public debt (PBD) and a set of enlisted control variables (X) that shows a more predictive power towards REC - Financial development (FD), Gross Domestic Product Per Capita (GDPPC), Urbanization (URN), Carbon dioxide emissions (CO2), this captures our first objective. Accordingly, the baseline is given as:

$$Y_{it} = \alpha_i + \delta X_{it} + \emptyset Z_{it} + \gamma_{it} + \varepsilon_{it} \tag{1}$$

Where i and t signify countries and years, respectively. Y is the REC; X is a vector of our variable of interest, that is PBD and Z represents a vector of control variables; γ and ε are country fixed effect and noise effect respectively, and α, β, and γ are parameters to be estimated. In this study, we postulate that $\delta < 0$, that is, it is expected to exert a reducing impact on REC. The control variables (Z) were selected taking into account FD, GDPPC, URN, and CO2. The parameter estimates and their respective a priori expectation are $\emptyset > 0$. It implies that, theoretically, these variables are expected to boost access to renewable energy. Details of the variables are captured in Table 2. Treading on the path of the second objective which accounts for the impacts of public debt on renewable energy which may differ across the regions in SSA, by grouping the sample into sub-sample as thus: Central Africa, East Africa, West Africa, and South Africa. For the preliminary analysis, we ascertain the descriptive properties of the variables via descriptive and correlation analysis (see Tables 3 and 4 respectively).

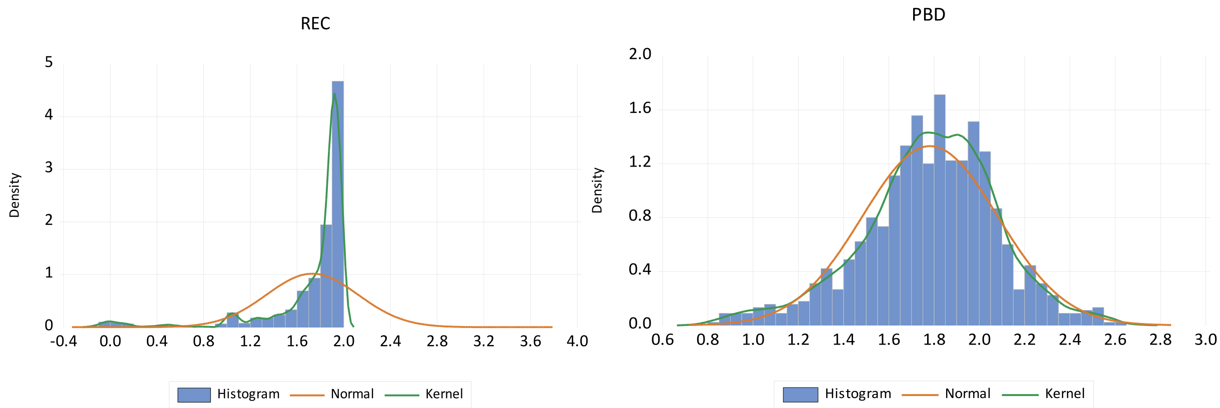
The use of IV-GMM is motivated by the following reasons: it takes care of endogeneity, omitted variable(s) bias, and autocorrelation issues (Dzator et al., 2021). It is efficient in the N>T dimension (that is, the number of cross sections higher than time periods). Thus, the instrumental variable generalized method of moment (IVGMM) method can take care of variable omission bias, gives consistent estimates, and produce efficient outcomes in the presence of unknown heteroscedasticity as compared to its orthogonality requirement (Baum et al., 2002). This technique is also reliable and valid as it is estimated in a single step (Cameron and Trivedi, 2005). To validate the instruments' authenticity and model reliability, diagnostic tests like Kleibergen-Paap F-statistics and Hansen J are tested. In the sub-regions, we conducted a two-stage least squares (2SLS) technique that is robust when external instruments are weak and also used to observe structural parameters in regression models with endogenous regressors (Lewbel, 2012). It creates heteroskedasticity-based instruments from the auxiliary equation residuals multiplied by each exogenous variable in mean-centred form. According to Lewbel (2012), a two-stage least squares estimator does not rely on usual exclusion limits and delivers similar estimates to external instruments. Therefore, the instrumental variables employed include the lag of the explanatory variables.

4. Empirical results and discussions

4.1. Descriptive statistics

Table 3 presents the descriptive statistics results of both the full sample and SSA sub-regions. For the full sample, the findings indicate that the average values of renewable energy (REC), public debt (PBD), financial development (FD), economic growth (GDPPC), and urbanization (URN) are 66.088, 74.499, 0.989, 29.587, 2206.675 and 39.939 respectively. Also, the result shows that their corresponding standard deviations are REC (27.236), PBD (53.077), CO2 (1.755), FD (98.745), GDPPC (2925.952), and URN (16.276). This shows that GDPPC has the highest average value followed by PBD and then REC. For the case of SSA sub-regions, we observed that the highest average value of GDPPC is 4121.095 (Southern Africa), followed by 3243.117 (Central Africa) and 2287.427 (Eastern Africa) with 999.387 for Western Africa as the least mean value. In all the subsamples, GDPPC has the highest mean value followed by PBD and REC. By taking the series' normality into account, we can further our investigation. Fig. 1 displays the results of the normality tests, which reveal a highly peaked distribution for REC and a significant departure from a normal (symmetric) distribution; in contrast, the public debt exhibits some normality; thus, this asymmetric relationship invites additional empirical investigation.

Fig 1: Normality plots of Renewable Energy (REC) and Public Debt (PBD) on the Full Sample



Source: Authors Computation

Table 3: Descriptive statistics

Full Sample	REC	PBD	CO2	FD	GDPPC	URN
Mean	66.088	74.499	0.989	29.587	2206.675	39.939
SD	27.236	53.077	1.755	98.745	2925.952	16.276
MIN	-60.649	6.44	0.022	-1.238	-781.255	5.416
MAX	98.304	434.907	9.093	1647.029	15061.470	100.417
Central Africa						

Mean	68.104	69.631	0.973	14.648	3243.117	49.947
SD	10.387	48.528	1.452	8.481	3793.522	21.663
MIN	45.371	9.216	0.049	1.153	132.041	18.082
MAX	98.3037	264.443	4.598	427.651	12523.052	100.417
East Africa						
Mean	66.214	77.113	1.361	20.316	2287.427	25.553
SD	33.108	36.772	2.150	25.312	39.886	14.554
MIN	0.310	17.114	0.023	-1.238	327.226	5.416
MAX	96.053	202.136	9.231	76.843	14115.233	61.246
Southern Africa						
Mean	45.277	46.107	1.366	48,691	4121.095	44.988
SD	29.023	27.615	2.546	72.286	2859.837	13.418
MIN	3.190	6.431	0.067	5.386	316.22	23.566
MAX	87.354	138.392	8.569	4312.102	9931.448	78.264
West Africa						
Mean	69.026	86.821	0.308	23.712	999.387	40.813
SD	20.162	65.843	0.231	25.427	648.204	10.523
MIN	12.628	7.277	0.034	0.021	28.376	13.619
MAX	94.842	434.907	1.143	396.622	3624.072	68.218

Source: Authors' Computation

4.2. Correlation analysis

The correlation analysis presented in Table 4 indicates that all the explanatory variables in the full sample have a negative relationship with REC. A similar result was observed in the Eastern and Western regions of Africa, while in the Central region, GDPPC has a positive association with REC. PBD has a positive relationship with REC in the Southern region. A robust check from post-estimation reported in Appendix 2, the VIF and the mean value are all significantly below the theoretical redline, and thus a confirmation of the absence of multicollinearity in the selected model.

Table 4: Correlation analysis

FULL SAMPLE	REC	PBD	CO2	FD	GDPPC	URN
LREC	1.000					
LPBD	-0.061	1.000				
LCO2	-0.616	-0.193	1.000			
LFD	-0.499	-0.135	0.344	1.000		
LGDPPC	-0.460	-0.235	0.885	0.096	1.000	
LURN	-0.398	-0.057	0.682	0.204	0.537	1.000
Central Africa						
LREC	1.000					
LPBD	-0.175	1.000				
LCO2	-0.148	0.118	1.000			
LFD	-0.694	-0.059	0.104	1.000		
LGDPPC	0.094	0.027	0.873	-0.012	1.000	
LURN	-0.346	0.009	0.715	0.581	0.566	1.000
East Africa						

FULL SAMPLE	REC	PBD	CO2	FD	GDPPC	URN
LREC	1.000					
LPBD	-0.537	1.000				
LCO2	-0.562	0.225	1.000			
LFD	-0.164	-0.281	0.064	1.000		
LGDPPC	-0.740	0.217	0.861	0.007	1.000	
LURN	-0.735	0.018	0.735	-0.240	0.617	1.000
Southern Africa						
LREC	1					
LPBD	0.521	1				
LCO2	-0.745	-0.103	1			
LFD	-0.892	-0.028	0.624	1		
LGDPPC	-0.894	-0.381	0.719	0.264	1	
LURN	-0.783	-0.375	0.635	0.683	0.625	1
West Africa						
LREC	1					
LPBD	-0.821	1				
LCO2	-0.484	-0.148	1			
LFD	-0.62	-0.25	0.385	1		
LGDPPC	-0.673	-0.301	0.623	0.305	1	
LURN	-0.675	-0.063	0.378	0.375	0.476	1

Source: Authors' Computation

4.3. Main Results

The IV-GMM result (See Table 5) for the full sample indicates that public debt (PBD), carbon emission (CO2), financial development (FD), and economic growth (GDPPC) exert a negative and significant linkage with REC. Specifically, in model 1, a percent increase in the use of these variables reduces REC by 0.41%, 0.23%, 0.30%, and 0.50% respectively in sub-Saharan Africa. Urbanization (URN) has a positive and significant influence on REC. The negative influence of public debt on REC means that a unit rise in public debt will bring about a significant reduction in REC thereby showing that public debt reduces the consumption of renewable energy in SSA. This could be linked to the hypothesized environmental impact of debt overhang theory which averred that in a situation where the possibility of public debt could eventually be higher than the nation's capacity to repay, this could rub off the economy from investing in low-carbon emissions such as renewable energies. This outcome is also plausible given that SSA's governments have historically given less emphasis to renewable development in favour of perceived more pressing issues like health, education, agriculture, and employment opportunities among others. Similarly, renewable energy requires a significant amount of resources and is perceived to be very risky, hence, SSA governments prioritize other basic infrastructure. On the other hand, this outcome is equally expected given SSA's history of corruption and public funds misappropriation resulting in inadequate government program implementation and diverting scarce resources from being invested in clean energy (Dimnwobi et al 2022b). The outcome of our study on debt-renewable energy consumption supports the neoclassical viewpoint that government debt is harmful to economic progress which in turn drags government investment in eco-friendly economic activities, and aligns with the growing empirical evidence of Hashemizadeh et al. (2021), Wang et al. (2020) and Jianhua (2022) in emerging, BRICS and Asian nations respectively but contradicts the earlier outcomes of Przychodzen and Przychodzen (2019) and Florea et al. (2021). A thriving financial industry is thought to have a positive effect on the development of the renewable energy sector. Howbeit, based on the findings, financial development appears to be impeding the development of renewable energy in SSA and this outcome matches Saibu and Omoju (2016), Kwakwa (2020), and Ankrah and Lin (2020) while contradicting the outcomes of Eren et al. (2019), Anton and Nucu (2019) Asongu and Odhiambo (2020), Raza et al. (2020), Qamruzzaman and Jianguo (2020), Khan et al. (2020), Dimnwobi et al (2022a) and Somoye et al (2022). A probable justification for this outcome is that renewable projects are capital-intensive and most financial institutions in SSA consider these projects to be risky, hence they charge huge interest rates on loans for such projects. This makes it more difficult for developers to undertake such projects thereby undermining renewable energy development (Ankrah and Lin, 2020). Another explanation can be attributed to the structure and focus of SSA's financial sector as it seems that the bulk of financial institutions exists to provide personal or individual services. For example, consumer or retail banking is more prevalent among banks in the regions than project financing (Ankrah and Lin, 2020).

Furthermore, our study confirmed that increased CO2 emissions reduce REC, aligning with previous studies in SSA (Baye et al., 2020 for 32 SSA economies, in SSA; Oluoch et al 2021 for 23 SSA economies and Bayale et al., 2021 for 8 SSA nations). A possible reason for this outcome is that SSA is a predominately fossil-fuel-powered economy (Oluoch et al 2021; Dimnwobi et al, 2022c). Carbon emissions are a significant by-product of fossil energy sources and their expansion indicates a rise in the usage of fossil fuels and a decline in the consumption of renewable energy

It is expected that as economies' incomes rise, they will have greater financial resources to invest in clean energy sources. This is also known as the income hypothesis. However, our study revealed that economic growth deters REC in SSA. The possible justifications for this finding could be (i) The complex nature of debt utilization and its impact on renewable energies in SSA (ii) the continual reliance on traditional energy sources to grow the SSA economy (iii) Inadequate commitment by the government to invest in renewable energy, insufficient knowledge of the existence of renewable energy sources, the massive capital investment required for renewable energy production and ignorance of the risks linked with increased non-renewable energy usage as domiciled in (Kwakwa, 2020). This study corroborates with the results of Ergun et al. (2019), Kwakwa (2020), and Dimnwobi et al (2022a) but contradicts the results of Gozgor et al. (2020), Zhao et al. (2020) and Oluoch et al. (2021). Urbanization promotes renewable energy consumption. It demonstrates that the urban population is significantly reliant on clean energy. This is because urbanization reclaims chances for resource-efficiency agglomeration, hence expanding the usage of clean energy technology. Also, greater employment options are available to persons who live in urban areas and with higher income, they consume environmentally friendly goods. Another explanation for this outcome is that people residing in urban areas are relying less on traditional energy sources and embracing clean energy sources. Our results align with Malik et al (2014), Akintande et al. (2020) and Bayale et al (2021)

Regionally, the coefficient of public debt exhibits a significant negative association with renewable energy consumption across the four regional blocs of Africa. This outcome lends credence to the notion that public debt is utilized in funding projects that rely on non-renewable energy sources. Financial development (FD) is found to have a significant negative association with renewable energy consumption (REC) in the sub-regions except for the Eastern region where it was insignificant. This contradicts the premise that the expansion of the financial industry will boost clean energy and reinforces the long-aged debate posited on the underdeveloped nature of the financial system in the SSA economy. This outcome could be explained by the fact that financial institutions in the regional blocs in SSA have not been supporting the shifts towards clean energy and this could stymie the blocs from achieving most of the sustainable development goals. Also, another reason for this outcome is contingent on the fact that financing renewable energy initiatives entails risks and these risks could include uncertainties caused by future climate regulations as well as the extended payback times of renewable energy investments (Somoye et al, 2022). Carbon emission ($CO2$) also has a significant negative linkage with renewable energy in the regions except for Southern Africa where the coefficient was positive and significant. This outcome shows that among all the SSA regional blocs, Southern Africa is the only sub-region that is conscious of global warming. The danger that $CO2$ emissions bring to the environment can encourage the usage of renewable energy. Analogously, renewable energy has become crucial to mitigating rising emissions as a result of various commitments to reducing $CO2$ emissions under international accords.

Economic growth (GDPPC) exerts a negative and significant relationship with REC in EA, SA and WA but has a positive and significant impact on REC in CA (Central Africa). This implies that Central Africa may have attained the requisite level of economic growth to allow for lower amounts of carbon emissions. An increase in income can encourage people to use less traditional energy sources and to switch to more efficient clean energy sources. Finally, urbanization (URN) does not have any significant linkage with REC in Central Africa but it significantly adds to REC in the Eastern region and significantly reduces REC in both Southern and Western Africa. The outcome for Southern and Western Africa could be explained by the fact that rapid urbanization leads to an increase in energy demand and to satisfy these demands, the governments in these regional blocs prioritize fossil-based energy sources over renewable energy sources. This outcome is consistent with Baye et al. (2020).

To test the viability of the IV-GMM approach, we subjected the techniques to four post-estimation or diagnostic tests. The tests include the Kleibergen-Paap LM statistic, Crag-Donald Wald F-Statistic, Kleibergen-Paap Wald F statistic, and Hansen J statistic, all indicating that our estimates are free from invalid instrument problems. Upon the hypothesis of the under-identified model, the Stock-Write LM test reveals that the coefficient on the change in the independent is equal to zero and the over-identifying constraints are valid across specified models. The Hansen J statistic equally confirms the accuracy of the estimating instruments. The coefficient of multiple determinations, R^2 which measures the changes in the dependent variable explained by the independent variables, ranges from 0.601 to 0.8843 implying that about 87%, 88%, 81%, 79% and 60% respectively of variations in the dependent variable is explained by the explanatory variables across the models.

Table 5. Result for Aggregate SSA sample and SSA sub-regions (Dependent Variable: REC)

Variables	Model 1 (Full Sample)	Model 2 (CA)	Model 3 (EA)	Model 4 (SA)	Model 5 (WA)
LPBD	-0.416***	-0.114	-0.521***	-0.042***	-0.130***
	[0.011]	[0.020]	[0.012]	[0.031]	[0.031]
LCO2	-0.231***	-0.402***	-0.413****	0.235***	-0.134*
	[0.014]	[0.312]	[0.076]	[0.025]	[0.016]
LFD	-0.302***	-0.256***	-0.094	-0.431***	-0.225***
	[0.040]	[0.015]	[0.027]	[0.026]	[0.011]
LGDPPC	-0.501***	0.374***	-0.215***	-0.486***	-0.235***
	[0.023]	[0.038]	0.102	[0.034]	[0.032]
LURN	0.441***	0.145	0.815***	-0.782***	-0.463***
	[0.043]	[0.051]	[0.121]	[0.082]	[0.038]
Constant	1.211***	0.782***	1.312***	3.531***	1.127***
	[0.325]	[0.211]	[0.251]	[0.243]	[0.128]
Diagnostics tests					
Kleibergen-Paap LM statistic	5.527	5.142	5.314	4.735	5.861
P-value	0.113	0..137	0.121	0.173	0.106
Crag-Donald Wald F-Statistic	897.365	618.474	863.661	663.793	1032.328
Kleibergen-Paap Wald F statistic	1032.214	958.251	1165.448	996.126	794.562
Hansen J statistic	0.452	3.734	1.621	2.346	1.648
p-value	0.217	0.103	0.116	0.241	0.138
Observations	870	150	180	150	390
R^2	0.8722	0.8843	0.8081	0.7915	0.601

Source: Authors Computation

Note: Robust standard errors in parentheses [ ]; Probability values represented as *p < 0.10, **p < 0.05, ***p < 0.01. CA - Central Africa, EA - Eastern Africa SA- Southern Africa, and WA-West Africa.

4.4. Robustness analysis with Two-Stage-Least Square estimation

To confirm the reliability and robustness of our result and the technique used, we adopted the 2SLS estimation technique which also takes care of endogeneity problems such as in the case of IV-GMM. The results of 2SLS estimation also confirm a similar outcome with the IV-GMM regression model as illustrated in Table 6. Firstly, public debt, carbon emission, and financial development significantly reduce renewable energy consumption in SSA. The 2SLS estimation suggests that a 1% rise in public debt (PBD), carbon emission (CO2), and financial development (FD) reduces renewable energy consumption (REC) by 0.305%, 0.376%, and 0.292% respectively in the full sample of SSA. For urbanization, the 2SLS estimation also reveals that a 1% rise in urbanization enhances the consumption of renewable energy by 0.100%. Contrarily, the outcome of GDPPC (economic growth) indicates a positive and insignificant association with REC. In all, the outcome of 2SLS confirms that IV-GMM is reliable.

Table 6: Two-stage-least Square Result (Robustness check)

Variables	Model 1 (Full Sample)
LPBD	-0.305***
	[0.034]
LCO2	-0.376***
	[0.048]
LFD	-0.292***
	[0.025]
LGDPPC	0.003
	[0.049]
LURN	0.100***
	[0.024]
Constant	2.270***
	[0.255]
Diagnostics tests	
Anderson canon. corr. LM statistic	789.226
p-value	0.000
Crag-Donald Wald F-Statistic	2807.488
F*	187.85
Prob > F	0.000
Sargan statistic	0.988
p-value	0.319
Observations	870
R2	0.976

Source: Authors Computation
Note: Robust standard errors in parentheses [ ]; Probability values represented as; *p <0.10, **p <0.05, ***p <0.01.

5. Conclusion, Policy Implications, and Future Research Agenda

5.1. Conclusions

Discussions for the transition to the use of renewable energy have grown louder as concerns about the growing effects of climate change around the world have increased. Since renewable energy is crucial to a nation's development and environmental progress, it has consequently attracted more attention and debate globally. A plethora of studies has been devoted to determining the implications of a variety of variables, including economic growth, financial development, urbanization, carbon emissions, and external trade, among others, due to the predicted increase in global future energy demand. Regardless of the existence of these empirical studies and their contrasting conclusions, the inadequate attention devoted to the role of public debt in funding renewable energy investments, particularly by developing regions, makes our study inquiry essential. In SSA, which has abundant renewable energy potential but is still energy-poor, this study looked at the effect of public debt on the consumption of renewable energy. Specifically, this paper assessed renewable energy consumption as a function of public debt, carbon emission, financial development, economic growth, and urbanization, covering 29 SSA nations between 1990 and 2020. It did so by estimating total renewable energy consumption in connection to other specified predictors, based on previous empirical studies and reviewed economic theories. For the data analysis, the descriptive properties of the variables were examined through descriptive and correlation analysis, while the IV-GMM and two-stage least squares techniques were conducted for the general SSA region and separate sub-regional blocs respectively. While the 2SLS empirical assessments conducted for the four SSA regions (Central, East, South and West) show interesting findings, the IV-GMM result for the full sample indicates that public debt (PBD), carbon emission (CO2), financial development (FD), and economic growth (GDPPC) exert negative and significant linkage with the renewable energy, while urbanization (URN) has a positive and significant influence on REC.

5.2. Policy Implications

Given our study findings, the following recommendations become pertinent: regional policymakers should consider the possibilities of public debt to encourage investment in the renewable energy sector. Public debt in the region should be employed to finance increased investment in renewable energy initiatives to promote the growth of renewable energy consumption. Additionally, government debt-based finance is a pivotal component of the drive towards effective energy transition to realize the global net-zero carbon target and other climate agreements. Therefore, the government in the region needs to undertake productive and sustainable investments in the field of clean alternative energy sources through the use of public lending, tax incentives, and fiscal concessions for energy production, as well as open and fair energy sector governance. Renewable energy initiatives like the African Development Bank's recent "Facility for Energy Inclusion" (FEI) program, which offers a $500 million debt-financing vehicle for small-scale alternative energy projects and off-grid solutions, should be utilized by SSA nations. SSA economies have to become more innovative with the administration of current fiscal space to maintain macroeconomic stability in light of the uncertain worldwide macroeconomic prospects following the post-COVID recovery efforts, the detrimental consequences of the Russian-Ukraine crisis, and the fragility of the SSA economies. Likewise, the capacity to increase fiscal stimulus and fund budget deficits should motivate policymakers to give heed to corruption-free public spending decisions to avoid a debt-distress that could undermine financing towards the region's energy sector.

SSA governments should prioritize reducing CO2 emissions more in their plans for national and regional development. The transition to renewable energy in the region should be intensified going on the negative relationship between CO2 emissions and renewable energy use from our study findings, to preclude the possibility of future environmental damage. By guaranteeing transparency in the potential funding for enhanced environmental quality and climate change mitigation, the region should demonstrate its commitment to international climate agreements and the global sustainability agenda. Even though a good number of SSA nations are unlikely to have reached the GDP per capita threshold necessary to permit lower carbon pollution levels, they should work to implement policy initiatives that guarantee renewable energy projects adhere to the strict criteria of "Clean Development Mechanism projects" (CDMs). This will increase their ability to gain from global carbon markets, which provide about $100 billion annually to initiatives in developing nations targeted at climate change mitigation and adaptation. To boost the proportion of clean energy and the sustainability of the energy sector in SSA nations, the dedicated implementation of carbon caps and trade programs should also be encouraged.

The consumption of renewable energy has been shown by our findings to be negatively impacted by financial development, suggesting that the financial sector has not contributed to the advancement of renewable energy in the SSA region. This necessitates that policymakers direct additional financial business toward encouraging the capital-intensive development of the renewable energy industry. African finance industry engagement is crucial for decision-makers to reinvent how funds are allocated in a changing global environment since Africa is the continent most exposed to climate change. To garner sufficient global financial capacity to enhance local innovation and promote climate-resilient and low-carbon development on the continent, Africa's financial sector operators must collaborate creatively. Determining the trajectories that direct financial flows to the development of Africa's renewable energy sector will be made possible by strengthening continental initiatives like the "African Financial Alliance on Climate Change (AFAC)", which seeks to place the financial sector at the heart of climate intervention in Africa. Additionally, SSA can activate a regional renewable finance strategy in cooperation with financial sector operators to galvanize a corporate movement of capital to regional renewable energy and ecologically sustainable development in accordance with the goals of AFAC. Among other things, financing under such a program will further entail raising incremental operating capital for the creation of new renewable energy enterprises and the extension of current renewable energy projects in the region. As a result, this will offer creative options for microgrid renewables, promoting localized economic development in rural communities, bringing down the price of electricity, and increasing access to energy.

Again, the findings of the study show that renewable energy and Gross Domestic Product Per Capita have a negative relationship in SSA. This signifies that the nations, businesses, and individuals in SSA have not made sizable investments in the development and utilization of renewable energy to support the growth in the region. This is possibly the consequence of poor energy literacy among the populace, a lack of knowledge about the presence of clean energy sources, high capital costs associated with generating renewable energy, insufficient government investment in renewables, and a lack of awareness of the risks linked to rising non-renewable energy consumption. The findings that growth has a detrimental effect on renewable energy is yet another evidence that economic expansion has not been sufficiently environment ally friendly to affect how much renewable energy is utilized in SSA. This raises the possibility that the region's economic status has not yet progressed to the point where a high consumption of renewable energy becomes the norm. Again, this further suggests that, across several SSA nations that have weaker incentives to engage in renewable energy technology, income from fossil fuels continues to make a significant contribution to GDP per capita in these countries. Clean growth of the SSA economy can also be achieved by generating employment in green energy technologies and projects to raise welfare standards. SSA countries need to also promote the development of their economies by encouraging the use of renewable energy. To do so, national economic growth policies in the region should emphasize and incentivize the use of renewable energy in all spheres of economic endeavors.

Positively, our findings show that urbanization has a beneficial and considerable impact on SSA's usage of renewable energy. Planning for urban expansion should be synchronized with the use of greener energy sources to maintain this favorable outcome in the region. The implementation of an urban renewable energy strategy that maximizes the efficiency and greening of the entire energy supply chain should be considered in urban planning. The government should also effectively limit the continuous utilization of fossil fuels, particularly in large cities. Furthermore, SSA's urban expansion and energy strategy should incorporate promoting global best practices in the benchmark for energy efficiency and effective energy consumption operations. The such regional strategy should also prioritize avenues to provide businesses and households more access to affordable financing for the purchase of energy-efficient products, financial development at national and regional levels should also improve awareness of and allocation of green finance for urban dwellers.

5.3. Limitations and Agenda for Future Studies

Although this research was able to shed some light on the public debt-renewable energy nexus in SSA, it also has several potential drawbacks. Our research was limited to the economies of 29 SSA nations between 1990 and2020.Hence, because of likely peculiarities, our conclusions should not be instantly applied to entire Africa and beyond. For broader comparison insights, other research could be undertaken that involves different parts of the globe. The finance of renewable energy, aside from public debt, may also be impacted by the other contexts of fiscal policy and warrants investigation. It is also erroneous to assume that the predictive variables used in this study are the sole factors that affect the application of renewable energy in SSA. Considering that we only examined a limited set of economic factors that affect renewable energy in SSA, future investigations on other factors, particularly fiscal incentives, subsidies, and regulatory and governance indicators, will be useful. Additionally, only data from a specific period, a limited number of countries (29 SSA nations) owing to data availability, and a couple of econometric methods are used in the current analysis. The scope of the data sets and/or the number of countries can be expanded by further studies. Likewise, as econometric techniques continue to evolve, alternative and more contemporary methods of panel data analysis should be recognized by subsequent research.

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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: Variance Inflation Factor (VIF)

	Full sample	Central Africa	East Africa	South Africa	West Africa
VIF	≤1.55	≤1.16	≤1.46	≤1.26	≤1.52
1/VIF	≤0.64	≤0.53	≤0.86	≤1.34	≤0.65
Mean VIF	1.32	1.26	1.44	1.20	1.58
Decision	No multicollinearity				

Source: Authors Computation

Note: ***p < 0:01 indicates statistical significance at 1% level; Theoretically, if VIF exceeds 10 and the Average/Mean VIF exceeds 6, there is presence of problem of multicollinearity in the model.