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Turning the tide on energy poverty in sub-Saharan Africa: Does Public Debt Matter?

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Abstract

A popular theme in the literature is the examination of a variety of factors that contribute to energy poverty, but little is known about the connection between public debt and energy poverty, particularly for developing regions of the world. This study clearly illustrates the nexus between public debt and energy poverty, focusing on thirty SSA nations from the years 2007 to 2018. In conjunction with disaggregated energy poverty variables such as urban electrification, national electricity access, rural electrification, access to clean cooking fuels, renewable energy utilization and output, a composite energy poverty index was developed using the principal component analysis and estimated in relation to public debt via the Instrumental Variable Generalized Method of Moments approach.Additionally, the effects of a debt threshold are taken into account and their implications for the region's energy poverty are assessed. The main finding of the study reveals that public debt has a positive and significant linear effect on the energy poverty index, national electricity access, urban electrification, rural electrification and access to clean cooking fuels while it reduces renewable energy production and utilization. Thus, our research contributes to the body of knowledge and offers policy recommendations for SSA's targeted reduction in energy poverty through sustainable public debt management.

Keywords: Public Debt, Energy Poverty, Sub-Saharan Africa, Debt Threshold, Electricity Access.

1. Introduction

Energy is a critical economic enabler. It is essential for meeting fundamental human requirements and attaining adequate living conditions. However, access to affordable and clean energy is not a global reality, resulting in the concept of energy poverty (EP) (Hosan et al., 2023; Murshed & Ozturk, 2023). The International Energy Agency statistics reveal that in 2019, 770 million and 2.6 billion individuals across the globe were without electricity access and clean cooking facilities, respectively. As reported by World Health Organization (2018), around 3 billion people utilize solid fuels to meet their various domestic needs globally, resulting in 4 million deaths annually as a result of illness from household air pollution. In many developing nations, access to reliable and affordable electricity remains one of the most significant barriers to reducing poverty, improving health, and promoting economic outcomes (Garba & Bellingham, 2021; Salman et al., 2022). The exigency of available and affordable clean energy is recognized as one of the Sustainable Development Goals (SDGs) (Erdoğan et al., 2022). This objective of widespread modern electricity access (Goal 7) and the reduction of EP could be accomplished with strong political will, policymakers' commitment, and investments in energy infrastructures (Ozughalu & Ogwumike, 2018; Adusah-Poku et al., 2021; Dimnwobi et al., 2023).

Addressing EP concerns requires committed funding of the energy sector due to its capital-intensive nature. Public debt represents one of several finance options for energy sector investments, making it an essential source of government energy spending in the face of tax revenue challenges and spending cuts (Yusuf & Mohd, 2021). A major justification for public debt is contingent on the neoclassical growth model, which encourages capital-scarce nations to borrow to boost capital accretion and attain a steady-state output per capita level (Yusuf & Mohd, 2021). Global economic crises have provided additional impetus for nations (particularly developing economies) to borrow, given the associated economic challenges and the need for improved expenditure levels (Joy & Panda, 2020). According to conventional wisdom, public debt boosts economic development in the short run by stimulating aggregate demand and output. On the flip side, the theoretical literature largely points to a long-term negative connection between debt and economic expansion as a result of private investment displacement through a crowding-out effect (Mhlaba & Phiri, 2019).

Among developing regions globally, the decision to pinpoint sub-Saharan Africa (SSA) as a case study is appropriate and strategic. Globally, the population without access to electricity has steadily reduced, from 1680 million in 2000 to 770 million in 2019(IEA, 2020). The same time frame witnessed an increase in the population lacking electricity in SSA from 506 million to 578 million (IEA, 2020). Likewise, statistics from the IEA (2020) show a wide disparity between rural and urban electrification in SSA, with 76% and 29% having access to electricity in urban and rural regions, respectively. As noted by Nwokoye et al. (2017), priorities are always given to urban regions when providing electricity infrastructure in SSA. Analogously, there are over 905 million individuals in the region who are without access to modern cooking facilities(IEA, 2019).The continuous reliance on traditional fuels has diverse negative effects on the quality of life and the environment (Dimnwobi et al., 2021). On the other hand, with electricity consumption per capita of 487 kWh, the region ranks among the world's lowest in terms of electricity use, trailingboth world and low and middle-income averages of 3,128 kWh and 1,927 kWh, respectively (World Bank, 2020). The foregoing highlights the EP plight of SSA with repercussions for the socio-economic development and the environment as significant investment effort is needed to address this shortfall.

The rate of public debt build-up in SSA nations has accelerated in recent years, creating fears among observers of an impending debt crisis(Atingi-Ego et al., 2021; Okafor et al., 2022). The impact of SSA's growing public debt on her economy has been the subject of contemporary debate, despite the stance of various governments in SSA that borrowing is necessary for reducing EP in particular and achieving several SDGs in general. More so, the extant literature contends that EP should be regarded as a critical component of sustainable development because of its general development implications (Adusah-Poku et al., 2021), encompassing welfare, inequality, and health outcomes (Oum, 2019) as well as the environment (Dimnwobi et al., 2021). Following major debt cancellations grantedto several SSA nations in the early to mid-2000s as part of the various debt relief programs, the public debt-to-gross domestic product (GDP) ratio decreased from 63% in 2001 to 28.9% in 2011 (IMF, 2021). These actions, together with robust growth and increased country solvency, created greater room for fresh borrowing. Despite these advancements, recent trends reveal that SSA nations have accumulated significant debts, with the public debt-to-GDP ratio reaching around 57.8% in 2020 (IMF, 2021).

There are several channels through which public borrowing may influence EP. The first is infrastructure investments. Lack of access to contemporary energy sources, such as electricity and clean cooking fuels, frequently causes EP. Governments may need to invest in energy infrastructure like transmission lines, power plants, and distribution networks to overcome this issue. Howbeit, these investments necessitate substantial financial resources, which may exceed the government's available budget (Onuoha et al., 2023a). Consequently, to fund the necessary infrastructure projects and reduce EP, governments may turn to borrowing, which would increase the national debt. Another channel through which public debt influences EP is economic growth. Economic expansion depends on having access to cost-effective and reliable energy. On the other side, EP restricts productivity, impairs access to healthcare and education, and lowers business operations, all of which inhibit the potential for economic progress. Governments may undertake measures targeted at increasing energy availability to encourage economic growth and reduce EP. Howbeit, such measures frequently necessitate substantial government expenditures, which can strain the budget and result in greater public debt. Sustainable economic growth is critical for managing public debt and avoiding debt burdens that outweigh the advantages of reducing energy poverty (Onuoha et al., 2023b)

Lastly, through the provision of energy subsidies, public debt can influence EP. Governments frequently offer energy subsidies to lower-income households, especially in developing nations, to make electricity cheaper for them. These subsidies may take the form of direct cash assistance or price caps on energy-related goods and services. Subsidizing energy, on the other hand, can strain state resources and contribute to the building of public debt. Governments have the option of borrowing to keep these subsidies in place or reforming them by progressively eliminating them while increasing spending on renewable energy and energy efficiency measures (Farooq et al., 2023). It is critical to notice that these theoretical connections can interact and influence one another. For instance, rising public borrowing may prevent a government from making investments in energy infrastructure, which could lead to the continuation of EP. Similarly, EP can impede economic development, thereby lowering the government's ability to service its debt and making it more difficult to properly address the issue.

This paper investigates the nexus between public debt and EP by extending prior studies in six different ways. First, to our knowledge, this study represents the pioneer effort to exclusively assess the implications of public debt on EP in the extant literature. Second, we focus on SSA because the pace of public debt in the region has been startling, and the region is one of the world's energy-impoverished regions despite possessing enormous natural deposits. EP is one of the biggest issues in SSA because a sizable percentage of the populace lacks access to dependable electricity and clean cooking facilities (Onuoha et al., 2023a; Onuoha et al., 2023b). To effectively create policies and strategies to address this critical issue, it is essential to comprehend the connection between public debt and EP. On the other hand, SSA is extremely sensitive to the consequences of climate change (Ulucak et al., 2020). Finding sustainable energy solutions that help mitigate climate change while also tackling EP is critical for the region's long-term growth and resilience. To finance sustainable energy projects and expand access to clean energy, this study is desirable. Finally, by investigating the connections between public debt and EP, policymakers and stakeholders can devise targeted interventions and long-term funding methods to guarantee that rising public debt does not stymie efforts to reduce EP and promote inclusive development in the region. Third, unlike mainstream EP literature that captures EP using only access to electricity, we adopt an inclusive strategy to capturing EP by employing six proxies of EP, namely, national electricity access, urban electrification, rural electrification, access to clean cooking fuels, renewable energy utilization and output to provide a more robust comprehension of the influence of public debt on EP. Fourth, we examined the non-linear connection between public debt and EP. Given an impending debt crisis in SSA despite the debt cancellations granted to nations in the region, it appears vital to indicate to policymakers a debt threshold above which access to contemporary and clean energy can be jeopardized. Fifth, the outcomes will be useful in addressing EP in SSA. Recently, achieving the SDGs has been a key component of the domestic development policy agenda. The use of energy services is closely linked to SDGs such as poverty reduction, inequality cutback, as well as emissions reduction to combat climate change. It ties these important development goals together with the goal of universal access to energy. For sustainable economic progress in SSA, rigorous and effective policy decisions necessitate a deep macro-level understanding of the implications of public debt and EP in SSA. As a result, the current study will aid SSA policymakers in developing frameworks and policies geared toward achieving SDGs by 2030. Lastly, we applied advanced econometric techniques to produce a robust outcome to inform policies that will set an example for other regions of the world with similar challenges as the one being investigated.

The following sections make up the remainder of the paper. The next section contains a review of the literature, while section 3 covers the estimation approach. Section 4 presents the key findings before concluding in Section 5

2. Review of Literature

Over the last decade, scholars have been particularly interested in EP reduction. Several studies have been prompted by insufficient electricity access and increasingly complicated energy sources, particularly in developing economies. The discussion on EP is rapidly gaining traction, with research interest focused on the determinants, dimensions, and potential solutions (Apergis et al., 2021). Since there are no studies on public debt on EP (as far as we know), the empirical review is divided into two: studies focusing on the drivers of EP as well as those studies on the implications of macroeconomic variables on EP. The majority of studies on the predictors of household EP are conducted in African and Asian nations because these regions are among the energy poorest in the globe (Ozughalu & Ogwumike, 2018; Dimnwobi et al., 2021). These studies have identified community factors, household head, and household characteristics as the major variables that drive EP (Ozughalu & Ogwumike, 2018; Crentsil et al., 2019; Ashagidigbi et al., 2020). For instance, Ogwumike and Ozughalu (2015) and Ozughalu and Ogwumike (2018) used the logit model and found that EP in Nigeria is majorly driven by household size, age, region of residence, educational level, and gender of the household head. Likewise, Ashagidigbi et al. (2020) discovered that age, land size, male-headed households, and residing in a rural area enhance EP while financial accessibility and income reduce EP. In a similar study for Ghana, Crentsil et al. (2019) found variables like household head age, area of residence, sex, and educational level as the critical drivers of EP. Analogously, Abbas et al. (2020) utilized data from six South Asian giants and established that residential location, household size, and household head's age as the significant EP drivers in the selected countries considered. Koomson and Danquah (2021) and Dogan et al. (2021) discovered that inclusive finance considerably reduced EP in Ghana and Turkey, respectively, using household-level data.

These studies above have investigated EP from the micro-level and largely reported that EP could be driven by individual, household, or community characteristics. Notwithstanding the relevance of these micro studies to the extant literature, they are incapable of addressing the implications of macroeconomic issues on EP (Dimnwobi et al., 2022a). Hence, it is essential to investigate EP from a macro-level perspective. In what follows, we present the sparse studies that have appraised the implications of macro variables on EP. Nguyen et al. (2021) utilized data from 65 economies to unearth the implications of financial expansion on EP between 2002 and 2015. The study found that EP is significantly reduced by financial development. Previous studies such as Anton and Nucu (2019), Eren et al. (2019), Khan et al. (2020), Qamruzzaman and Jianguo (2020), and Asongu and Odhiambo (2020) discovered that financial development is essential to the utilization of renewable energy. Nguyen and Su (2021a) appraised the influence of government spending on EP reduction in 56 developing economies between 2002 and 2015. The study found, among other things, that public expenditure reduces EP. In more recent inquiries, Chien-Chiang et al. (2022) highlighted that innovation in renewable energy (RE) technologies reduce EP in China. Likewise, in China, between 2004 and 2017, Dong et al. (2022) reported that EP could be eradicated in China by inclusive financial development. In a related study in China, Wanjun et al. (2022) concluded that EP is exacerbated by increased country risks and fiscal decentralization. Relatedly, Mohsin et al. (2022) discovered that the advancement of the financial sector in Latin America is critical to reducing EP in that region. In a study in Nigeria, Dimnwobi et al. (2022a) confirmed that Nigeria's EP is exacerbated by insufficient public capital expenditure. Zhao et al. (2022) discovered that China's green growth is negatively correlated with EP. This suggests that China's green growth will significantly benefit from the alleviation of EP. Similarly, Acheampong et al. (2022) documented that income inequality exacerbates EP in SSA. In 32 African economies between 2005 and 2016, Murshed and Ozturk (2023) demonstrated that improving energy efficiency, transitioning to renewable energy, and financial advancement all contribute to reducing EP by lowering the rates of electricity inaccessibility in African countries.

Public debt could theoretically exert various influences on economic outcomes. According to the debt overhang argument, when a country's debt stock surpasses a certain threshold, adding to it would likely result in net negative returns since the marginal cost of debt will likely be higher than the marginal gain. As a result, debt has a detrimental influence on economic outcomes. On the other hand, the Keynesian view explains debt as a country's asset because persistent deficit expenditure may be seen as crucial to a country's economic advancement (Whajah et al., 2019). The connection between public debt and access to clean energy is still unclear in the extant literature. Some studies have assessed the implications of public debt on the utilization of renewable energy. For example, Florea et al. (2021) and Przychodzen and Przychodzen (2019) established that public debt increases the demand for renewable energy in the European Union and transition economies, respectively. Conversely, Wang et al. (2020), Hashemizadeh et al. (2021) and Jianhua (2022) reported a decrease in the consumption of RE as a result of public debt. In more recent studies, Onuoha et al. (2023a) employed the feasible generalized least squares on a sample of 29 SSA economies between 1996 and 2020 to establish that renewable energy consumption is positively influenced by public borrowing. Similarly, Onuoha et al. (2023b) employed the same scope and IV-GMM to document that public borrowing reduces the utilization of renewable energy

On the other hand, the literature has also appraised the influence of public borrowing on ecological preservation. For instance, Zeraibi et al. (2023) discovered that public borrowing in developing countries reduces environmental damage. Similarly, Farooq et al. (2023) established that public borrowing had a positive and significant impact on ecological performance in Organization of Islamic Cooperation (OIC) nations from 1996 to 2018. Sadiq et al. (2022) assessed the importance of external debt in increasing environmental performance in developing countries from 1990 to 2019. The authors discovered that external debt promotes environmental sustainability. Analogously, Carrera and Vega (2022) discovered that foreign debt accelerates environmental deterioration in 78 rising economies between 1990 and 2015. In a comparable study for China, Qi et al. (2022) revealed that public borrowing induces significant reductions in urban emissions.

3. Methodology

3.1. Empirical Model

Building from the past empirical and theoretical standpoint (Pachauri & Spreng 2011; González-Eguino 2015; Wang et al. 2020; Hashemizadeh et al. 2021; Nguyen &Su, 2021a), the framework to guide the functional empirical baseline model specification is ascertained. It is shown thus:

$$lny_{it} = \alpha_{it} + \beta lnpud_{it} + \gamma lnZ_{it} + \varepsilon_{it} \quad (1)$$

The variables are captured in their respective natural logarithmic form, shown by the notation "ln". Other notations in Eq. (1) include "it" for the ith country in year t and ε the stochastic error term. α_{it} is the constant of the functional relationship, whereas β and γ respectively, represent the elasticity coefficients of public debt (PUD); Z denotes a vector of all the control variables (gross domestic product per capita (GDPPC), urbanization (URB), trade openness (TRO); y is the vector of energy poverty (EPV1..EPV6).A composite index for EP indicators is formed using the principal component analysis (PCA) using the following formula, thus;

$$PCAindex = \sum_{i-1}^{n} w_i FV_i \quad (2)$$

PCA is used to identify the relative contributions of each indicator to the total variance explained by the variables, which is denoted by FVi in Eq. (2). Individual contributions to the standardized variance of PC1 are used as weights (wi) in an estimation of the PCA as a linear combination of the six variables used as proxies for EP. The model is extended to account for the turning point (inverted U-shaped) relationship:

$$lny_{it} = \alpha_{it} + \beta lnpud_{it} + \varphi lnpudsq_{it} + \gamma lnZ_{it} + \varepsilon_{it} \quad (3)$$

Where $lnpudsq$ indicates the square public debt, it shows that public debt contributes to access to clean and contemporary energy sources at the early stages of loan award; however, once a threshold level of debt to GDP is achieved (at this point, repayment loan becomes a burden), further borrowing can induce a shift away from access to modern and clean energies and toward EP and use of dirty fuel. Accordingly, a valid inverted U-shaped relationship between public debt and EP exists if $\beta > 0$ and $\varphi < 0$ and will indicate that the incidence of high debt stock is strong enough to trigger EP, and this is valid when there is a statistically significant causal relationship between β and φ on y; other possible options will predict a deviation from the valid inverted U-shaped relationship and possible account for monotonic or U-shaped relationship. The turning point of this representation is obtained by setting the derivative of Eq. (3) equal to zero, which yields $lnpud_{it} = -\beta/2\varphi$.

3.2. Estimation Techniques

First, we deal with one of the biggest problems in cross-country econometrics by looking at the Pesaran (2004; 2015) cross-sectional dependence (CSD) in panel data set and Pesaran and Yamagata (2008) slope heterogeneity test.These methods take into account heterogeneity and

CSD. Second, the Instrumental Variable Generalized Method of Moments (IVGMM) is adopted as the main estimation technique. The idea behind IV-GMM is that it is better than ordinary least-squares when endogeneity, autocorrelation and omitted variable(s) bias are present (Ndubuisi et al., 2022). It works well when there are more cross-sectional units than time periods (N>T). Therefore, even when the heteroscedasticity is uncertain, the IVGMM can handle variable omission bias, provides consistent estimates, and produces satisfactory results. This is in contrast to the orthogonality requirement of the method (Baum et al., 2002). In one step, we figure out how reliable and valid this method is (Cameron & Trivedi, 2005). Diagnostic tests like Kleibergen-Paap F-statistics and Hansen J are taken into account to ensure that the instruments are real and that the models are accurate.

3.3. Data source and description

This paper utilized annual data to unearth the implications of public debt on EP with the variables chosen based on theoretical considerations and empirical literature adoption. Following Wang et al. (2020) and Hashemizadeh et al. (2021), we utilized public debt (% of GDP).In alignment with previous studies (Apergis et al., 2021; Nguyen et al., 2021;Nguyen &Su, 2021a; Nguyen &Su, 2021b;Dimnwobi et al., 2022a; Dimnwobi et al., 2022b), we adopted six EP proxies namely national electricity access, urban electrification, rural electrification, clean cooking fuels access, renewable energy (RE) consumption and RE output. Furthermore, the study employed three control variables, namely trade openness (TRO), gross domestic product per capita (GDPPC), and urbanization (URB). These variables were included in the model because of their various roles in determining EP.Except for data on public debt which was sourced from the Historical Public Debt Database of the International Monetary Fund (IMF), other variables (See Table 1) were collected from World Bank World Development Indicators (WDI). The research covers 30 SSA nations (see Appendix A) spanning the years 2007 to 2018, with this period selected based on data availability. Table 1 contains the data summary.

Variable	Measurement	Source
Public debt (PUD)	% of GDP	IMF Data
National electricity access (EPV1)	% of population	World Bank (WDI) Data
Urban electrification (EPV2)	% of urban population	World Bank (WDI) Data
Rural electrification (EPV3)	% of rural population	World Bank (WDI) Data
Access to clean fuels and technologies for cooking (EPV4)	% of population	World Bank (WDI) Data
RE consumption (EPV5)	% of total final energy consumption	World Bank (WDI) Data
RE output (EPV6)	% of total electricity output	World Bank (WDI) Data
Urban population (URB)	% of total population	World Bank (WDI) Data
Trade openness (TRO)	% of GDP	World Bank (WDI) Data
Gross domestic product per capita (GDPPC)	Constant 2010 US$	World Bank (WDI) Data

Table 1: Data Description

Source: Authors Compilation

4. Results Presentation

4.1. Summary Statistics and correlation analysis

Table 2 depicts the descriptive statistics and correlation analysis of our variables. It reveals that GDP has the highest average value of 2495, followed by trade openness (73), EPV2 (70), EPV5 (62), PUD (49), EPV1 (43), URB and EPV6 (41 each). The standard deviations for most of the variables are far less than their respective mean values, which implies that there is no wide variation from the mean. For instance, standard deviations for EPV2, EPV5, PUD, EPV1, URB, and EPV6 are approximately 19, 25, 32, 25, 15, and 32, respectively, while that of GDPPC shows wide variation from its mean as its standard deviation is higher than its mean value. The skewness for EPI (energy poverty index), EPV2, and EPV5 are negatively skewed, while the rest of the variables are positively skewed. Also, EPI, EPV1, EPV2, EPV5, EPV 6, and PUDsq have kurtosis values less than 3. This means that they are platykurtic, and as such, the series is flat relative to normal distribution. On the other hand, EPV3, PUD, GDPPC, and TRO have kurtosis values greater than 3, which implies that the series has a long tail with a peaked curve and, as such are leptokurtic, while EPV4 and URB have kurtosis values equal to 3 suggesting that the series have a normal distribution and are mesokurtic.

The correlation resultpresented in the lower part of Table 2shows that for the baseline model (EPI), all the explanatory variables (PUD, PUDsq, GDPPC, URB, and TRO) have positive relationships with the compositeindex of EP. Similar results were observed in the EPV1 model (national electricity access), EPV2 model (urban electrification), EPV3 (rural electrification), and EPV4 model (access to clean cooking facilities), whereas the explanatory variables exhibit a negative correlation with both the consumption of renewable energy and renewable electricity production models.

	EPI	EPV1	EPV2	EPV3	EPV4	EPV5	EPV6	PUD	PUDSQ	GDPPC	URB	TRO
Descriptive Statistics												
Mean	1.529	43.310	70.415	25.280	26.909	62.674	41.247	49.799	2.665	2495.262	41.113	73.011
Median	1.578	38.368	74.882	16.958	15.750	75.267	40.094	43.343	2.679	1214.650	39.611	62.547
Maximum	1.960	100.000	100.000	100.000	100.000	93.587	105.400	174.915	5.030	13606.090	88.559	225.023
Minimum	0.717	4.800	11.860	0.225	0.200	0.709	0.034	6.440	0.654	42.413	16.208	1.378
Std. Dev.	0.278	25.851	19.568	27.466	30.576	25.673	32.657	32.578	0.919	2981.608	15.653	37.514
Skewness	-0.486	0.664	-0.565	1.500	1.148	-0.989	0.262	1.327	0.175	1.770	0.692	1.313
Kurtosis	2.383	2.520	2.613	4.290	3.142	2.743	1.759	4.694	2.691	5.096	3.420	5.194
JB	19.865	29.873	21.382	159.975	79.317	59.674	27.208	148.645	3.275	253.813	31.407	175.550
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194	0.000	0.000	0.000
Obsv	360	360	360	360	360	360	360	360	360	360	360	360
Correlation Matrix												
EPI	1.000											
EPV1	0.928	1.000										
EPV2	0.917	0.860	1.000									
EPV3	0.747	0.868	0.660	1.000								
EPV4	0.733	0.853	0.629	0.798	1.000							
EPV5	-0.605	-0.686	-0.469	-0.741	-0.798	1.000						
EPV6	-0.300	-0.357	-0.322	-0.370	-0.356	0.467	1.000					
PUD	0.116	0.122	0.133	0.207	0.136	-0.182	-0.097	1.000				
PUDSQ	0.097	0.116	0.120	0.198	0.152	-0.205	-0.017	0.958	1.000			
GDPPC	0.649	0.806	0.547	0.740	0.896	-0.672	-0.360	-0.002	-0.018	1.000		
URB	0.613	0.676	0.473	0.373	0.579	-0.434	-0.197	0.016	0.009	0.616	1.000	
TRO	0.381	0.439	0.300	0.430	0.575	-0.587	-0.003	0.179	0.202	0.580	0.322	1.000

Table 2: Descriptive statistics and correlation matrix
Source: Authors Compilation

4.2. CSD and Slope Heterogeneity Tests Results

Table 3illustrates the outcome of the Pesaran cross-section dependence test adopted to check if data are correlated across groups (in this case, countries). The null hypothesis asserts that there is no cross sectional dependency of data across sections, while the alternative hypothesis counteract s it. According to Dong et al. (2018), in dynamic panels where the number of cross-sectional units is more than the number of time periods (N>T), it is crucial to test for cross-sectional independence to prevent an ineffective and misleading result. Table 3indicates evidence of CSD. So, we reject the null hypothesis of no CSD and estimate the IV-GMM,which can effectively take care of heterogeneity issues among data series. We also tested for slope heterogeneity using Pesaran and Yamagata (2008) test (see Table 4).

Variable	CD-test	p-value	average joint T	mean ρ	mean abs(ρ)
EPI	42.587	0	12	0.59	0.7
EPV1	52.966	0	12	0.73	0.75
EPV2	34.1	0	12	0.47	0.64
EPV3	20.801	0	12	0.29	0.4
EPV4	34.811	0	12	0.48	0.72
EPV5	15.951	0	12	0.22	0.43
EPV6	-0.086	0	12	0	0.41
PUD	14.344	0	12	0.2	0.46
PUDSQ	15.055	0	12	0.21	0.46
GDPPC	40.947	0	12	0.57	0.72
URB	42.491	0	12	0.59	0.91
TRO	5.394	0	12	0.07	0.41

Table 3. Result of the CSD test

Notes: Under the null hypothesis of cross-section independence, CD ~ N(0,1); P-values close to zero indicate data are correlated across panel groups. Source: Authors Compilation

Table 4 represents the slope homogeneity test which is employed to test if the slope coefficients of cointegration equations are homogeneous. This was originally developed by Swamy (1970) and later improved by Pesaran and Yamagata (2008). The null hypothesis states that slope coefficients are homogenous as against the alternative hypothesis of heterogeneous. However, since both simple (delta tilde) and mean-variance bias adjusted (adjusted delta tilde) have probability values less than a 5% level of significance for all our variables, it means that we reject the null hypothesis and conclude that there is slope heterogeneity in our data. Thus, the paper adopts a dynamic panel model (see Table 5)

Model Specification	Delta tilde	p-value	Adjusted delta tilde	P-value
EPI	5.177	0.000	8.02	0.000
EPV1	5.44	0.000	8.428	0.000
EPV2	5.215	0.000	8.078	0.000
EPV3	3.136	0.000	4.858	0.000
EPV4	6.254	0.000	9.689	0.000
EPV5	5.307	0.000	8.222	0.000
EPV6	3.584	0.000	5.552	0.000

Table 4. Pesaran and Yamagata (2008) slope heterogeneity test
Source: Authors Compilation

4.3. Main Results and Discussions

Table 5 displays the outcome of the IV-GMM estimations. Model 1 is the baseline model with composite EP index computed via PCA as the dependent variable, while models 2-7 are the disaggregated EP variables starting from EPV1 to 6, respectively (as already defined in section 3.3). In the composite EP index model, the results show that public debt (PUD) at a linear level has a positive and significant influence on the index of EP. Specifically, a one percent increase in public debt will increase all the EP indicators by 0.123 percent points in SSA. This also shows that the accumulation of public debt drives national electricity access, rural and urban electrification, access to clean fuels for cooking, and renewable electricity production and consumption. The outcome suggests that public debt can reduce EP in SSA.

However, when the EP index is disaggregated into the various indicators, namely national electricity access (EPVI), urban electrification (EPV2), rural electrification (EPV3), clean cooking fuels access (EPV4), renewable energy consumption (EPV5), and renewable energy output (EPV6), the result shows that public debt has a significant positive influence on EPV1-EPV4. This implies that public debt is effective in boosting access to clean cooking fuels and technologies as well as electricity access (national, urban, and rural areas). This outcome aligns with the Keynesian model, which avers that effective utilization of public debt can boost the economy's productive capacity, thereby driving economic expansion and infrastructure development. The outcome of our study on the effectiveness of debt in enhancing access to modern energy aligns with Florea et al. (2021) and Przychodzen and Przychodzen (2019), who earlier obtained that public debt is critical in the utilization of clean energy sources. On the other hand, public debt reduces renewable energy production and consumption corroborating prior studies like Wang et al. (2020), Hashemizadeh et al. (2021),and Jianhua (2022) that established in their various case studies that public debt engenders reduction in the utilization of renewable energy. The likely justification for this outcome is that most SSA governments perceived investments in renewable energy to be extremely risky; as a result, SSA governments prioritize other basic infrastructures considered to be less risky. The outcome of our study corroborates a recent report by the International Renewable Energy Agency and the African Development Bank which stated that despite Africa's huge renewable energies potentials, in the last two decades, the region received only 2% of global investments in renewable energy.The coefficients of PUB and

PUBsq are both positive and negative, respectively and validate the inverted U-shape relationship between public debt and EP. Put in another form; public debt contributes to EP reduction at the early stages of borrowing; however, once a threshold level of debt is achieved, further borrowing can induce a shift away from access to modern energy and toward dirty or EP. A further explanation for this novelty is that in the SSA region, emphasis is still at the scale stage of borrowing, where the attention is more on borrowing rather than on means of utilizing and channelling the fund to provide modern energy to society. Considering model renewable energy consumption (EPV5) and renewable electricity output (EPV6), public debt (PUB) and its square are both negative and positive statistically significant, validating the U-shape hypothesis.

Economic growth (GDPPC) tends to improve the EP scenario in SSA. This is confirmed by the study's outcome, which established that the influence of economic growth on all the indicators of EP is positively significant. This suggests that economic expansion stimulates electricity access in national, rural, and urban regions as well as access to clean cooking facilities and renewable energy production and consumption. This finding's plausibility is embodied in the fact that economic expansion can encourage people to use less traditional energy sources, which deteriorate the environment and is harmful to health and to switch to more efficient modern energy consumption practices. Furthermore, the empirical outcome is supported by both supply and demand-side channels. As SSA's economy expands, it is expected that the region's energy stock, particularly those derived from contemporary energy sources, will grow as well. As a result, the expansion in economic growth can help to increase the availability and accessibility of modern energy sources. Increased income is also expected to increase people's ability to afford clean energy resources. This outcome is consistent with Florea et al. (2021); Hashemizadeh et al. (2021); Acheampong et al. (2022); Jianhua (2022); Wanjun et al. (2022) but contradicts Ankrah and Lin (2020); Anton and Nucu (2020); Dimnwobi et al. (2022a) and Dimnwobi et al. (2022c)

Another important outcome of this study is that increased urbanization is linked with a reduction in EP. This is confirmed by the positively significant relationship between urbanization and all the EP indicators. The results are in alignment with the conclusions of Akintande et al. (2020),Bayale et al. (2021), and Hashemizadeh et al. (2021). These findings can be attributed to the fact that urbanization provides higher employment opportunities, and with increased employment options, there will be increased income growth which will lead to the consumption of modern and clean energy sources. Analogously, since priorities are given to urban areas in citing energy infrastructures (Nwokoye et al., 2017), modern energy could be more accessible and affordable in urban areas, which will stimulate a transition away from traditional fuels in urban settings. Finally, trade openness was found to be ineffective in reducing EP in SSA. This is confirmed by the results in Table 5, which shows that trade openness has a negative relationship with the composite EP index while also reducing access to electricity in national, rural, and urban areas as well as also discouraging the use of clean cooking facilities and the production and utilization of renewable energy. This indicates that SSA's economy does not align with the technological transfer theory, which contends that when a nation opens up, unique expertise, information, and technology about modern energy sources will be accessible, fostering that nation's development. This outcome aligns with Linet al. (2016) and Hashemizadeh et al. (2021).

One interesting component of the results in Tables 5 and 6 is the inverted U-shaped relationship between EP and public debt. This suggests that EP is aggravated when a certain threshold level of debt stock is achieved (at this point, repayment loan becomes a burden); further borrowing can induce a shift away from access to modern or clean energy sources and toward EP and the use of fossil fuel. The turning point of 2.662-12.769% of debt to GDP is estimated as the threshold level of debt at which further borrowing loan triggers EP. This additional empirical insight explains why empirical findings from previous studies using panel selection of countries with different degrees of public debt and access to energy consumption have remained inconclusive in their policy recommendations. Below the threshold public debt of 2.662-12.769% of GDP, the economic contribution of public debt also supports access to modern energy sources by providing the resources to fund the acquisition of such environmentally friendly and clean energy sources. As economic dependence on public debt increases, the possibility of EP intensifies until the turning point is reached. As shown in Table 2, the mean of the public debt to GDP is 49.799, which is above the threshold public debt of 2.662-12.769% of GDP, indicating that the public debt burden has triggered the EP in SSA. From a policy perspective, SSA can break EPthrougha commitment to strong political will and investments in energy infrastructures.

VARIABLES	1	2	3	4	5	6	7
PUD	2.553**	2.689**	1.739**	1.257**	1.653**	-1.273***	-1.226**
	(1.407)	(1.446)	(0.905)	(0.532)	(0.925)	(0.413)	(0.545)
	[1.815]	[1.859]	[1.921]	[2.362]	[1.787]	[-3.076]	[-2.247]
PUDSQ	-0.767*	-0.810*	-0.520*	-2.537**	-1.899*	2.466***	4.155**
	(0.442)	(0.455)	(0.286)	(1.098)	(1.173)	(0.852)	(1.867)
	[-1.733]	[-1.781]	[-1.819]	[-2.310]	[-1.619]	[2.895]	[2.226]
GDPPC	0.511***	0.502***	0.199***	1.315***	1.545***	0.786***	0.897***
	(0.037)	(0.037)	(0.024)	(0.084)	(0.100)	(0.058)	(0.152)
	[13.728]	[13.551]	[8.343]	[15.715]	[15.524]	[13.651]	[5.914]
URB	0.322***	0.491***	0.087*	0.162*	0.126*	0.155*	0.099*
	(0.086)	(0.089)	(0.051)	(0.197)	(0.240)	(0.147)	(0.353)
	[3.727]	[5.521]	[1.692]	[0.821]	[1.524]	[1.052]	[1.280]
TRO	-0.133**	-0.120*	-0.073**	-0.514***	-0.090*	-0.111*	-0.786**
	(0.058)	(0.061)	(0.035)	(0.166)	(0.131)	(0.098)	(0.368)
	[-2.304]	[-1.958]	[-2.114]	[-3.096]	[-1.687]	[-1.933]	[2.133]
Threshold	0.979	1.089	0.452	1.595	1.570	1.570	2.547
Threshold (Total Debt as % of GDP	2.662	2.971	1.572	4.926	4.804	4.805	12.769
Constant	-2.411**	-2.751**	-0.202	-8.384***	-9.572***	10.848***	12.763***
	(1.080)	(1.109)	(0.694)	(2.686)	(2.864)	(1.994)	(4.558)
	[-2.232]	[-2.480]	[-0.291]	[-3.121]	[-3.342]	[5.440]	[2.800]
Diagnostic Test							
Kleibergen-Paap LM statistic	5.793	5.807	5.821	5.835	5.849	5.863	5.877
P-Val	0.122	0.401	0.68	0.959	0.238	0.517	0.796
Cragg-Donald Wald F statistic	425.546	108.372	208.802	525.976	843.15	160.324	177.498
Kleibergen-Paap Wald F statistic	56.722	78.129	99.536	120.943	142.35	63.757	85.164
Hansen J statistic	0.374	0.513	0.652	0.791	0.931	0.069	0.208
P-Val	0.507	0.102	0.303	0.708	0.113	0.518	0.923
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	360	360	360	360	360	360	360
R-squared	0.467	0.494	0.881	0.726	0.584	0.847	0.754

Table 5: IV-GMM result Debt-EP

Source: Authors compilation. Robust standard errors in ( ); t-statistics in [ ]; *** p<0.01, ** p<0.05, * p<0.1

The tests listed inTable 5 are reliable. With critical values between 5.613 and 5.69, the Kleibergen-Paap LM statistic, the Cragg-Donald Wald F statistic, and the Kleibergen-Paap Wald F statistic show that all the models are free from the weak instrument. This means that our research results do not have an invalid instrument problem. Under the null hypothesis that our model is under-identified, the stock-Wright LM test shows that the coefficient on the change in the independent is equal to zero and that over-identifying restrictions are valid across the model specifications. Also, the Hansen J statistic confirms that the instruments used in the estimation are correct. The R-squared number ranges from 0.467 to 0.881. It shows how the changes in the endogenous variable can be predicted by the changes in the independent variables. That is, between 46.7% and 88.1% of the changes in the amount of EP can be explained by factors that are not related to each other

4.4. Robustness check

Given that panel data estimation provides various econometric issues that affect parameter validity; consequently, we apply the defactored instrumental variable mean group (IV-MG) model established by Cui et al. (2020) and Cui et al. (2021) using Kripfganz and Sarafidis (2021) STATA algorithm that incorporates heterogeneous slope dynamics using defactored instrumental variables that absorb unobserved common components while accounting for omitted-variable bias, endogeneity, fixed-effects, and CSD.

Variables	1	2	3	4	5	6	7
PUD	0.123**	0.087**	0.051**	0.345**	0.190**	-0.018**	-0.699**
	[2.038]	[2.933]	[2.827]	[2.550]	[1.991]	[-2.222]	[-1.977]
PUDSQ	-0.040**	-0.019**	-0.013**	-0.116**	-0.065**	0.005**	0.139**
	[-1.962]	[-2.566]	[-2.674]	[-2.542]	[-2.086]	[2.175]	[2.163]
GDPPC	0.024**	0.002**	0.012**	0.084**	0.011**	0.015**	0.144**
	[2.317]	[2.123]	[2.026]	[1.955]	[2.098]	[1.934]	[1.887]
URB	0.295**	0.189**	0.251**	2.057**	0.335**	-0.070**	-3.481***
	[2.405]	[2.310]	[2.220]	[1.984]	[1.897]	[-2.112]	[-4.633]
TRO	-0.018**	-0.033**	-0.015**	0.195**	0.035*	-0.016**	0.020**
	[-2.762]	[-2.512]	[-2.559]	[1.812]	[1.859]	[-2.292]	[2.152]
Constant	0.935***	1.220**	1.508***	-3.013***	0.285***	1.874*	5.561***
	[3.943]	[1.969]	[4.783]	[-3.651]	[2.902]	[1.667]	[5.507]
Threshold	0.002	0.001	0.0001	0.020	0.006	0.0001	0.049
Threshold (Total Debt as % of GDP	1.002	1.001	1.000	1.020	1.006	1.000	1.050
Observations	360	360	360	360	360	360	360
Number of ids	30	30	30	30	30	30	30

Table 6: IV-Mean: Robust Check

Sources: Authors compilation. t-statistics in [ ]; *** p<0.01, ** p<0.05, * p<0.1

Focusing on the key variables, the results from Table 6 are as follows: (i) IV-mean result confirmed the positive and significant coefficient of public debt on the EP index as well as EPV1 to EPV4, which indicates that public debt has a significant positive influence on EPV1-EPV4. (ii) Also, the IV-mean group test verified that the coefficient of PUBsq exhibitsa negative and significant impact on EPV1 to EPV4. This shows that PUB and PUBsq validate an inverted U-shape relationship with EP indicators.This reinforces the theoretical episode of the debt overhang hypothesis, posting that when a country's debt stock surpasses a certain threshold, additional borrowing would likely result in negative net returns, which may lead to a marginal cost of debt that is likely higher than its marginal gain. This would trigger the movement toward dirty or energy poverty and away from access to modern energy.(iii) In the case of renewable energy consumption (EPV5) and renewable energy output (EPV6), the results show that public debt initially causes a decrease in energy poverty but that this effect is reversed after the debt is doubled. For the SSA economy, this means that public debt and energy poverty (renewable energy consumption (EPV5) and renewable energy output (EPV6) have a U-shaped relationship. The findings suggest that a debt-free government is better positioned to address energy poverty-related concerns. The government may be able to use loan funds to finance cutting-edge technology that can be used to boost access to modern energy. But as the debt mounts and repayment becomes a priority, the focus swings away from access to modern energy and toward dirty or EP.

5. Conclusion and Policy Recommendations

With a focus on thirty SSA nations and spanning the years 2007 to 2018, the goal of this study is to establish a possible connection between public debt and EP. This is because rising levels of public debt may make it more difficult for governments in the region to fund projects that would increase access to energy for underserved SSA communities and countries. Using the PCA, a composite EP index was derived and estimated in connection to public debt via the IV-GMM technique alongside disaggregated EP variables, namely national electricity access (EPVI), urban electrification (EPV2), rural electrification (EPV3), clean cooking fuels access (EPV4), renewable energy consumption (EPV5) and renewable energy output (EPV6). Also, given the likelihood of a non-linear association between public debt and EP, a debt threshold is considered and determined with implications for EP in the region. The study uncovered that public debt (PUD) at a linear level has a positive and significant influence on the index of EP, suggesting that public debt can lessen energy poverty in SSA. For the disaggregated energy poverty indicators, public debt was found to exert a significant positive influence on national electricity access (EPVI), urban electrification (EPV2), rural electrification (EPV3), and clean cooking fuels access (EPV4), respectively, while it reduces renewable energy consumption (EPV5) and renewable energy output (EPV6). Furthermore, our findings confirm the inverted U-shape association between public debt and EP by demonstrating that the coefficients of PUB and PUBsq are both positive and negative, respectively. Therefore, public debt increases EP from the time it is borrowed until it reaches a certain level of debt. Beyond this limit, borrowing causes a movement toward dirty or EP and away from access to modern energy. Likewise, our findings were corroborated by the defactored instrumental variable mean group (IV-MG) results of the positive and significant effect of public debt on the EP index as well as EPV1 to EPV4. In addition, PUB and PUBsq validate the inverted U-shape relationship with energy poverty indicators.

Furthermore, our study findings reveal that economic growth has a positive and significant influence on various energy poverty (EP) indicators in Sub-Saharan Africa (SSA). The expansion of the economy stimulates access to electricity in national, rural, and urban regions, as well as access to clean cooking facilities and renewable energy production and consumption. This can be attributed to the shift from traditional energy sources to more efficient modern energy consumption practices driven by increased income and affordability. The findings align with previous studies that support the relationship between economic growth and energy access. Additionally, the study highlights that increased urbanization is associated with a reduction in energy poverty, as urban areas provide more employment opportunities and prioritize the provision of modern energy infrastructure. However, trade openness was found to be ineffective in reducing energy poverty in SSA, contrary to the expectation that it would facilitate technological transfer and development. These findings provide valuable insights into the relationship between economic factors and energy poverty in SSA.

Given the inverted U-shaped connection between energy poverty and public debt in the study's findings, SSA governments may want to address the public debt threshold situation in relation to reducing EP by committing to fiscal consolidation. This would entail reducing the government's irrational fiscal behaviour (through actions like cutting wasteful expenditure, raising taxes, and reducing subsidies) and increasing revenue in the region to minimize the size of the budget deficit and, ultimately, reduce the level of EP. The next step is to advance conversations with creditors about debt relief and debt restructuring. Debt restructuring under circumstances where a nation's debt burden is unsustainable and debt forgiveness to lighten the load of public debt and increase fiscal space for energy sector investment, particularly towards renewable energy. Specifically, governments in SSA should look to international financial organizations for assistance, particularly in the form of financial and/or technical support for debt restructuring and fiscal consolidation. Beyond debt policy interventions, SSA policymakers should prioritize effective governance and transparent regulatory frameworks to attract investments in the energy sector and lessen overreliance on borrowing. This includes ensuring fair competition, protecting consumer rights, and creating an enabling environment for private sector participation. Strong regulatory institutions in the region will help ensure efficient and reliable energy services.

Control variables adopted in the study also elicit policy consideration in the debt-energy poverty discourse in SSA. For economic growth, SSA governments should prioritize policies that foster economic growth and income generation, particularly in rural areas, through investment in infrastructure, education, and job creation. The expected enhancement in economic opportunities will increase incomes, making modern and clean energy sources more affordable and accessible. Next, given the positive relationship between urbanization and energy access, governments should focus on well-planned urbanization strategies by providing adequate energy infrastructure, improving access to modern energy services, and promoting sustainable urban development practices. This is crucial to ensure that urbanization benefits are equitably distributed across countries in the region to avoid exacerbating inequalities. The findings on trade openness speak to the importance of fostering regional collaboration in SSA. Deepening collaboration among SSA countries can facilitate technology transfer, knowledge sharing, and joint initiatives to address energy poverty. Regional frameworks like the African Continental Free Trade Agreement (*AfCFTA*) should be leveraged to promote cross-border investments in energy infrastructure, facilitate regional energy trade, and encourage cooperation in research and development.

In general, the study stresses the position that SSA countries can harness the potential of public debt to improve energy access, reduce energy poverty, and advance sustainable development in the region. Consequently, SSA governments need to carefully manage their public debt and take into account any potential effects on a variety of sectors, including the energy sector, when making budget and policy decisions. Also, considering the findings of the control variables (namely TRO, GDPPC and URB), structural and economic reforms that can enhance the region's prospects for long-term growth and aid in lowering the debt-to-GDP ratio should be aggressively pursued. This can entail taking steps to enhance the business climate, increase private financing through financial development strategies for the region's energy sector, boost energy sector competition, and improve public sector efficiency and effectiveness. Lastly, leaders of SSA countries should carefully analyze their specific fiscal requirements and energy resources in addition to regional collaborative efforts. They should also endeavour to create domestic policies that are customized to their unique circumstances to actualize the twin objectives of debt sustainability and clean, affordable energy for all. Since this study's conclusions are not exhaustive, further investigation should explore linkages between public debt and governments' capacity to invest in energy infrastructure in other regional nations, how international aid and debt relief programs have affected governments' abilities to invest in energy infrastructure and how they have affected the impact of public debt on private investment in SSA's energy sector.

Appendix A: The Study Sample

Benin, Botswana, Burkina Faso, Cabo Verde, Cameroon, Central African Republic, Congo Republic, Cote d'Ivoire, Eritrea, Eswatini, Gabon, Ghana, Guinea, Kenya, Lesotho, Mali, Mauritania, Mauritius, Mozambique, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Zimbabwe

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