Energy 208 (2020) 118363

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Examining the linkages between electricity consumption and economic growth in African economies

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ARTICLE INFO

Article history:
Received 11 December 2019
Received in revised form
27 June 2020
Accepted 9 July 2020
Available online 15 July 2020

Keywords:
Electricity consumption
Economic growth
Energy intensity
Africa

ABSTRACT

As global energy consumption continues to increase, an increasing attention is also being drawn to the need to embrace cleaner energy despite ensuring energy security and efficiency in production. This study examines the relationship between economic growth and electricity consumption in sub-Sahara African economies between 1971 and 2017. It employs the System Generalized Methods-of-Moments (System GMM) techniques so as to address the issues of endogeneity in the data generating process. We also examine whether the impact of electricity consumption differs by the level of energy intensity, by employing an advanced dynamic panel threshold regression model to ascertain the degree of threshold level of energy intensity and the potential of threshold asymmetric of energy consumption on economic growth. Our results show significant positive relationship between electricity consumption and growth, including a threshold level of energy intensity which stood at 0.48%. This suggests that energy consumption beyond 0.48% will reduce growth, while consumption below this level will stimulate growth.

1. Introduction

Over the past decades, concerted efforts have been made to increase the energy base of the African economies. This is premised on the fact that energy is key to growth. As noted by Iyke [1]; electricity energy is core in energy bank building for both developed and developing economies. The reason for this has to do with issues related to climate change, energy crises, volatile oil prices, continuous and progressing carbon emission into the atmosphere and global warming among others. It is argued that effective energy policies tailored towards increasing electricity consumption can hamper greenhouse emissions and reduce climate change, and thus provide good platform for achieving sustainable growth [2–6].

Electric power is an essential component of economic activities; it enhances rapid and sustained industrial growth, technological progress and job creation. As African economies emerge into development, there is expansion in economic activities, increasing industrialization and urbanization. This connection between economic growth and electricity implies that as economic activities which require power supply increases, there will be a need for an increasing development of more power plants in order to meet the growing demand for energy [7]. It is therefore right to assume that increasing electricity consumption is an indicator of economic growth. This mechanism has been diagrammatically presented in Fig. 1. According to Fig. 1, the feedback hypothesis shows the conduit through which economic growth and electricity relates with each other, such that increase in one will stimulate improvement in the other. Opposite this flow is the growth-led chat that showcases the mechanism through which increase in economic growth will stimulate upward shift in the demand and supply for electricity. The figure also offers directions on the possibility of energy-led hypothesis where increase in electricity will lead to increase in economic growth. The figure reveals that a

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https://doi.org/10.1016/j.energy.2020.118363
0360-5442/

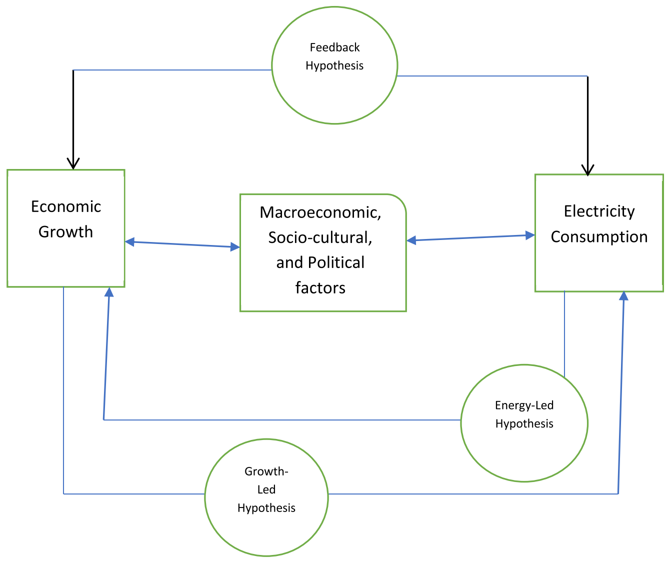

Fig. 1. Schematic of relationship between electricity consumption and economic growth.

unidirectional relationship exists between economic growth and electricity consumption for each of energy-led and economic growth-led hypotheses.

On the impact of the explanatory variables (macroeconomic, socio-cultural, and political factors) on the nexus between electricity consumption and economic growth, it can be argued that each of these variables induces functional relationship in the nexus. For instance, increase in trade implies internationalization of domestic trade by a way of increase in production opportunities so as to satisfy consumers demand (this will require some level of energy usage), increase in production capacity will improve on economic growth [8–10]. The same reason can be argued for financial development (FD), foreign direct investment (FDI) and other macroeconomic variables [11–14]. For the socio-cultural and political factors, for instance, life expectancy, primary school enrolment and government effectiveness are expected to aid growth which in turn led to increase in electricity. For instance, higher life expectancy suggest a long productive age [15]; propensity are high for literate population to be productive [16,17]; and high government effectiveness will enhance productive society [18–22] which spur up electricity consumption.

Theoretically, there are four clear cut possibilities of directional movement between economic growth and energy consumption. They include: (i) the energy-led growth hypothesis, that opined that energy consumption complements both capital and labor in the production process, thus, a declining energy consumption policy implies a fall in real GDP; (ii) the second possibility is related to the growth led-energy following hypothesis which stresses that a unidirectional causal relationship runs from GDP to energy consumption. This implies that policy framework that impedes energy consumption will have little or no significant impact on growth; (iii) the third possibility is the feedback hypothesis which suggests the existence of a bi-directional relationship between energy and growth; (iv) the fourth possibility is the neutrality framework which stresses that no relationship exists in either of the flips (energy-growth), thus reducing energy consumption will have no impact on growth, and vice versa [23].

Studies on the relationship between energy and economic growth became popular as a result of the 1973–1974 and 1978–1979 global energy crises [24–26]. These energy crises periods drew the attention of the world to the fact that energy and energy-based inputs are key to sustainable production processes [27]. This is evident in the continuous increase in the number of researches that attempts to examine the nature of the relationship between energy and economic growth. Though several studies have examined the nature of the relationship between energy and economic growth, the debate remains inconclusive as consensus as to which causes what is yet to be reached. For instance, while Apergis and Payne [28]; Apergis and Vouzavalis [29]; Ozturk and Acaravci [30]; Esen and Bayrak [31] and Iyke [1] are of the view that energy consumption causes growth, Aydin and Esen [32]; Hamit-Haggar [33]; Mehrara [34] and Menegaki [35] concluded that energy consumption has little or no significant relationship with growth. The divergent in results from these studies could be as a result of different methodologies used and different states of development in the economies studied.

Gozgor et al. [36] employed the panel autoregressive distributed lag (P-ARDL) and panel quantile regression (PQR) models to examine the impact of renewable and non-renewable energy consumption on economic growth using panel data sourced from some selected 29 OECD member countries from 1990 to 2013. The study observed that economic complexity as well as the duo of renewable and non-renewable energy consumption exhibits positive relationship with improvement in economic growth (see also [37].

Aydin and Esen [32] employed an advanced dynamic panel threshold regression model to test for the threshold level of energy intensity on growth within the context of symmetric behavior for some selected 12 commonwealths of independent states. The data coverage spanned from 1991 to 2013. The core objective of the study was to determine whether the effect of energy consumption on economic growth varies based on the level of energy intensity. The study noted that the energy thresholds level is at 0.44% for the economies studied, and that energy consumption above 0.44% will have a negative impact on economic growth, whereas energy consumption below 0.44% propels growth positively. The study advocates for more attention on energy intensity when national energy policy is made.

For Cameroon, Fondja [38] employed a three-step approach that first, examined the stationarity component of the data generating set; second, examined the causality between variables; and third, estimated the appropriate model in an attempt to examine the nature of the relationship between energy consumption and economic growth. The results reveal that the data set is non-stationary in nature, with causality running from energy to economic growth. The study further established cointegration among the variables with a possibility of a 1% increase in energy consumption leading to about 1.1% increase in economic growth. The study concluded that policy aimed at boasting energy consumption will lead to increase in economic growth; and that insufficient access to energy is a key obstacle to economic growth for Cameroon.

Sun and Kporsu [39] employed a parametric stochastic frontier approach with a calibrated Shephard distance model to examine the energy efficiency performance of some selected 71 developed and developing economies based on data sourced from 1990 to 2014. The study examined energy efficiency framework within the context of the role of institutional quality and green innovation technology; they observed that both institutional quality and green innovation impact positively on energy efficiency. The study further noted that economies like the US, Japan, Germany and Australia are the major leading states that have attained energy efficiency, while Ghana, Jamaica, Sierra Leone, Singapore, Iceland and Bahrain are the least energy efficient economies. The study raises a puzzle by showing that the level of development has little or no impact in attaining energy efficiency as shown in the case of Singapore, Bahrain, Malta with low energy efficiency scores of 67.75%, 79.29%, 69.46% respectively as against developing economies like Cameroon, Egypt, Pakistan, Morocco among others having 91.44%, 92.72%, 92.39%, 91.77% respectively.

For Turkey, Pata [4] examined both the long and short run dynamic relationships between per capita GDP, renewable energy and a host of other fundamental variables within the context of environmental Kuznets curve hypothesis. The study employed a few estimation techniques like the ARDL bounds test, Gregory-Hansen and Hatemi-J cointegration test to analyze data sourced from 1974 to 2014. The study established the existence of a long run relationship among the variables studied but could not established causality from either growth to energy, nor from energy to growth (see also [40].

For the Chinese economy, Zhao and Lin [41] calibrated the impact of foreign trade on energy efficiency-economic growth nexus, by employing a Tobit model-simultaneous equation to analyze whether foreign trade activities around Chinese textile industry impact on energy efficiency. The study reported that foreign trade impacts positively on energy efficiency especially from the import sub-sector. Other variables of significant influence include R&D input, ownership structure and energy price. The study suggests promotion of energy price reform such that energy price will reflect resource scarcity, as key to achieving energy efficiency.

Foon et al. (2016) examined the relationship between energy consumption and economic growth for the Vietnam economy, by employing the neoclassical Solow growth model. The study employed a series of estimation techniques such as Narayan-Popp unit root test, multivariate Johannsen cointegration test and Granger causality test. The study noted that energy consumption, foreign direct investment (FDI) and capital stock impact positively on economic growth. The study further noted that a uni-directional relationship runs from energy consumption to economic growth, suggesting that Vietnam is an energy-dependent economy. This implies that any energy conservative policy will have a negative consequence on economic growth. The study suggests massive investment in renewable energy, R&D among others in order to promote economic growth.

For the US economy, Carmona, Congregado, Feria, and Iglesias [42] employed a few econometric techniques to examine the nature of the relationship between energy consumption and economic growth with a focus on causality and persistence. The study was able to establish evidences suggesting the existence of nonlinear relationship and structural break in the model. The study further reported the existence of bi-directional relationship between energy and growth; and that both series are persistent, suggesting that cyclical and natural components are inter-dependent. The study warned against policies that aimed at reducing energy consumption, as such policies could deter growth, with huge potential of having permanent shocks (see also [43,44].

Wurlod & Noailly [45] calibrated sectorial analysis into the study of energy intensity by employing a translog cost function to examine the impact of green innovation on energy intensity for some selected OECD economies, based on data sourced from 1975 to 2005. The study noted that energy efficiency characterized by smart technology, green innovation, sustainable input substitution framework and autonomous technology changes are key to attaining reduced energy intensity, such that, 1% increase in these efficiency measure will lead to about 0.03% fall in energy intensity over the period studied.

For the Canadian economy, Gamtessa and Berhanu [46] employed panel vector autoregression, cointegration and error correction models to examine the impact of changes in energy utilization mixture as induced by changes resulting from modified carbon pricing policy. The study focused on knowing the effect of changes in carbon policy at both the long and short run. The study observed that energy price shock exerts significantly on energy-intensive sectors than non-energy intensive sectors. The study also noted that the effect of energy price changes on energy intensity is stronger in the short run than in the long run.

For the Chinese economy, Huang, Hao, and Lei [47] calibrated the roles of indigenous and foreign innovations on energy intensity based on data sourced from 2000 to 2013. The study employed the Driscoll-Kraay Standard error and panel cointegration techniques to examine the nature of the relationship among the variables analyzed. The study noted that indigenous technology plays a more significant role in reducing energy intensity than foreign technology. The study further observed that the impacts of foreign technological innovations on energy intensity is essentially influenced by the available technological absorptive capacity.

Chang, Wen, Zheng, Dong and Hao [48] calibrated the role of government efficiency to the energy efficiency and energy intensity discussion by employing the group-mean dynamic common correlated estimator (DCCE) regression, panel cointegration techniques and vector error correction model (VECM) to analyze a panel of data set from some selected 31 OECD countries based on data sourced from 1990 to 2014. The study noted that government efficiency significantly impacts on energy efficiency leading to a corresponding reduction in energy intensity level. The study identified left-wing government, strong anti-corruption framework and institutions, higher real per capita GDP and strong gross capital formation as factors that influence energy efficiency, while higher imported oil prices, stricter regulatory framework for the energy market are factors that provoke higher energy intensity for the studied economies.

Beyond determining the existence of a functional relationship between energy consumption and growth, it is also important to note that efficient use of energy (energy intensity) is key to sustainable growth [49]; [41,50–52]. As noted by Aydin [53] energy efficiency as a measure of energy intensity is a function of some salient factors like level of energy resources, climatic condition, and technological condition among others. A low energy intensity implies effective utilization of energy resources in the production of goods and services. It implies that productivity is enhanced with little energy consumption. This could imply a significant reduction in greenhouse emission and hurdles climate change. The point here is that, sustainable growth is better enhanced in an economy by its ability to increase her production base with less energy consumed. In other words, the ability of energy consumption to induce significant changes on economic growth depends on the level of energy intensity.

The essence of the current study is, therefore, to investigate the linkages between electricity consumption (as proxy for energy consumption) and economic growth in Africa sub region by employing a system GMM model. The study also intends to know if a functional relationship (bi-directional or unidirectional) exists in the model and whether or not the level of energy intensity plays a significant role in the linkage between the duo by following Aydin & Esen [32] to analyze the behavior of series. This is achieved by employing a dynamic panel threshold model that calibrates nonlinearity hypothesis into its framework. Examining this link between energy demand and growth is key to achieving sustainable growth (poverty reduction, improved welfare and job creation) and necessary for effective energy policies. For instance, in a bid to protect the environment and reduce imports, government may want to introduce measures like energy tax and other conservation policies, which could be harmful if it is an energy-leading growth system as such policy will lead to a fall in energy consumption with a corresponding fall in income. Whereas, this policy could be applicable when faced with economic growth-leading situation. For effective policy formulation, it is imperative for policy makers to understand the nature of the relationship between energy (electricity) and economic growth.

Our results suggest that a bi-directional relationship exist between economic growth and electricity consumption, this suggests that electricity consumption and economic growth are mutually dependent, thus policy directions should be towards promoting electricity consumption on the one hand and economic growth on the other hand. The results of the estimated threshold value at 48% which represent the level of the impact of energy intensity on growth. These results have some policy implications.

The rest of the study is organized as follows: Section 2 discusses the data and the methodology used, and Section 3 gives reports of the empirical results while section 4 concludes with relevant policy implications.

2. Data and methodology

Data for the current study was sourced from several reputable global data outlets. For instance, the data on the real gross domestic growth per capita, electric power consumption (kwh), real gross fixed capital formation (constant 2010) US $), labour, foreign direct investment, trade openness, Government spending and saving rate were sourced from the World Development Indicators (CD Rom, 2019). The data on inflation rates was sourced from the United Nations Statistics (UN Data). The data on agricultural output were sourced from the Economic Research service of the US Department of Agriculture (USDA). The ability of electricity consumption to influence economic growth is largely dependent on some salient socio-cultural and political factors, such as, government effectiveness,[1] life expectancy, fertility rate, level of education, among others. This is premised on the fact that sustainable growth driven by efficient energy system is achievable if an economy is able to balance the growth rate of individual (liberal) and collective (social) economic agents in such economy [54,55].[2]

Going forward, the current study followed [6,56–58] among others to calibrate some key socio-political factors that drives economic activities and of course the per capital growth into our team of explanatory variables. These variables are primary school enrollment rate (a proxy for education), life expectancy rate, governance effectiveness[3] and fertility rate. We employed data on primary school enrollment as a proxy for education/human capital development as against post primary education base on the fact that though post primary education data was available, it was at best available at 5–10 years interval. Data on life expectancy serve as a proxy of health status which reflect the socio-cultural well-being of the economies studied. The same is said of fertility rate. Governance variable suggest governance is a key driver o economic activity as it could determine the direction and pace of economic growth. Theoretically, we expect a positive relationship between economic growth and each of these socio-political variables, except fertility rate. A priori, we expect a negative relationship between fertility rate and growth as investment will be diverted to child-bearing and nurturing, against production of goods and services. Following [59], we selected 17 economies in the sub-Saharan Africa region. The selected economies are Angola, Cameroon, Congo, Cote D Ivoire, Ethiopia, Gabon, Ghana, Kenya, Mozambique, Nigeria, Senegal, South Africa, Sudan, Tanzania, Zambia and Zimbabwe. The data span from 1971 to 2017.

The core of the current study is to examine the link between energy consumption proxied by electricity consumption and economic growth within the confers of energy efficiency for some selected sub-Sahara Africa economies. The study relies on the neoclassical production function employed by Aydin and Esen [32]; Hamit-Haggar [33] and Menegaki [35]. The model for the study is presented as follows:

$$y_{it} = \beta_1 + \beta_2 y_{i,t-1} + \beta_3 EC_{it} + \beta_4 X_{it}\gamma + \delta_t + \phi_i + \varepsilon_{it} \quad (1)$$

where y represents the real GDP growth per capital at time $t$in country i, $y_{i,t-1}$ is the natural log of per capita GDP of country i in period $t-1$, EC represents energy consumption rate, X is a proxy for other macroeconomic variables that can influence economic growth such as foreign direct investment (FDI), agricultural output, foreign aid, trade openness and, labour, and ϕ_i is the time-invariant country effect, δ_t represents unobservable time effects while $\varepsilon_{it}$is the error term.

The GMM model as proposed by Arellano and Bond [60] for Equation (1) is as follows:

$$E(y_{it-s}\Delta u_{it}) = 0 \; for \; t = 3, \ldots, \; T \; and \; 2 \le T-1 \quad (2)$$

where y_{it-s} represents suitable lags of the dependent variables. This suggests that the second and further lags of the dependent variables are employed as an instrument for the residual of Equation (1) in differences. As pointed out by Heid, Langer and Larch [61] and Pereira and Cerqueira [44,62]; the estimator of Equation (2) is prone to huge small sample bias given the fact that the number of periods is small with the dependent variables showing high degree of persistence. To overcome this, we followed Arellano and Bover [63]; Berk et al. [64]; Hwang and Sun [65]; Phuc et al. [66]; Pothen and Welsch [67] and Su and Yin [68] to employ system GMM model which uses the following moment conditions.

$$E(\Delta d_{it-1}(\delta_i + u_{it}) = 0 \quad for \; t = 3, \; \ldots, \; T, \quad (3)$$

As established in literature, the initial level of GDP per capita which accounts for conditional convergence across countries is expected to be negative [57,69]. We also account for the impact of government spending on growth (excluding defense & education expenditures) to approximate the effects of non-productive government spending. Here, the prior expectation is negative. The effect of inflation on growth is also expected to be negative given that inflation generates uncertainty and unstable business environment [70]. We expect a positive relationship between economic growth and each of agricultural output, FDI, trade, saving rate [27,52,71]. The impact of net official development assistance and official aid received is largely influence by the quality of the institutional framework and bureaucratize efficiency. In a system characterized by poor institutions, bureaucratic incompetency and high level of corruption, aids will have negative impact on growth and vice versa[4] [32,57,72–75].

The presence of lagged endogenous variable y, $t-1$ in equation (1) makes it usually not to be estimated by ordinary least squares (OLS) fixed effects, or random effects panel data techniques [57] as it induces y_{it} to be correlated with ϕ_i, provokes upward biasness and inconsistent with the OLS assumption of independency of the error term from the regressors [60,76–78]. To overcome this problem, a few the existing studies on dynamic panel employed the

[1] Implies perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (WGI, 2019).

[2] Thanks to the anonymous reviewer that points our attention to these variables.

[3] Data on Governance effectiveness spanned from 1996 to 2017.

[4] we converted all the series into per capita unit using total population.

Arellano and Bond GMM techniques that employs internal mechanism to address the correlation between y, $t-1$ and ϕ_i. The GMM techniques removes ϕ_i, in short dynamic panels like Equation (1) by first differencing it. When we employed lagged values of the levels of the independent variables as predetermined variables, we obtained a relatively consistent estimator [57]. Specifically, when ϕ_i, (i=1, 2, …. N) are serially uncorrelated, then the second- and higher −order lags of the independent variables are valid instruments. As noted by Ref. [63,76–78], a major flaw of the [60] techniques is that poor instrument for the regressors in first differences is produced when the regressors displays persistence over time. The alternative to this setback was provided for in the [63,76,77] System GMM that estimates two sets of equations − A set in levels that employs lags of the regressors in first differences as instruments, another set of equation in first differences that employs lags of the regressors in level as instruments. As noted by Ref. [77], System GMM offers three advantages over the difference GMM; first, in reducing endogeneity bias; second reduces time-varying measurement error bias; third, reduces weak instrument error bias [62,66,78–81].

The current study therefore employed the system GMM to address the issues related to endogeneity resulting from the inclusion of y, $t-1$ the possibility of endogeneity of other independent variable base on the possibility that electricity generation and many of the other regressors may be jointly determined by the growth rate of the GDP, and the possibility of measurement errors owing to the use of cross country data that display high persistence. The study also examined the validity of the orthogonality assumptions of system GMM by employing the Hansen test of over identification and the Arellano and Bond test for second − order and higher-order serial correlation (AR(2)test), based on the fact that system GMM techniques depends on internal instruments. We followed [57] to use the [82] small sample correction of the standard errors in all two-step system analysis.

In order to examine the impact of energy intensity threshold on the link between energy consumption and economic growth, we followed [53,66,81] to employ the GMM dynamic panel threshold model as follows.

$$y_{it} = U_i + \beta_1 dec_{it} + I\left[\left(\frac{tpes}{Y}\right)_{it} \le \gamma\right] + \delta_1 I\left[(i_t \le \gamma\right] + \beta_2 dec_{it} I\left[\left(\frac{tpes}{Y}\right)_{it} > \gamma\right] + \varnothing z_{it} + \varepsilon_{it} \quad (4)$$

Here, dec_{it} is the growth rate of energy consumption per capita for both regime types; it is the vector of control variables, $tpes/Y$ is the threshold variable, β_1 *and* β_2 represents the regime coefficient, the endogenous variable is the initial income level y_{it-1} (see also [62,83,84].

It is important to note that, in employing the dynamic panel analysis techniques, the number of instrumental variables matters a lot, as it impacts on the results. This notwithstanding, the interchangeable linkages between the efficiency of the estimators and deviation in a finite sample framework is displayed by the number of instrumental variables. Furthermore, when we use all the possible lagged dependent variables as instrumental variables, it increases the efficiency of the estimator, whereas the estimated coefficients is neutral when just one lagged dependent variable is employed [32,85–87]. For this study in the first instance we used all the lagged values of the dependent variable as instrumental variables. Furthermore, we employed only one lagged value of the dependent variable as instrumental variable (the number of the selected instrumental variables has no significant effect on the results).

3. Results & discussion

The results of the current study are presented in two parts, first we present the result on the impact of electricity and other explanatory variables on economic growth based on system GMM estimation techniques. After we have established the existence of a functional relationship between electricity and economic growth in the studies economies, we examined in the second leg of our analysis, the role of energy intensity in the relationship between economic growth and electricity in the studied economies.

3.1. Impact of electricity on growth

In Table 1 we present the descriptive analysis of the variable used in the study. From Table 1, it can be deduced that trade has the lowest mean, while government spending has the highest mean value. The results from the standard deviation reveal that government spending still recorded the highest standard deviation while portfolio investment has the lowest standard deviation.

In Table 2, we present the results of the effect of electricity on growth. Columns (1), (2), (3), (4) and (5) present the results of the OLS, fixed effects, baseline system GMM and the alternative systems estimates for robustness purposes, respectively. As established in the previous section, OLS estimation of Equation (1) induces an upward biasness for the lagged per capita GDP, while a downward biasness is provoked by the fixed effects. According to literature, a consistent estimate is expected to lie between the OLS and fixed effect estimates (see Ref. [57,77]. The result as presented in column (3) of Table 2 shows that the two-step system GMM estimates on the coefficient on the lagged per capita GDP is − 1.649 and it lies between the downward biased fixed effect estimates − 5.429 and the upward biased OLS estimates of −1.131, with negative and highly statistically significant coefficient. These results provide platform to established existence of conditional convergence across the economies studies (see also [69,74,88].

The result of the impact of electricity on economic growth as presented by the two-step system GMM estimate is 0.1105 and highly significant at 1% level of significance. This implies that electricity promotes economic growth. To validate the credibility of our result, we test for over identification restrictions and second order serial correlation using the AR (2) test and Hansen test. The results of the P-value of the AR (2) test at 0.103 suggest that there is no significant evidence of second or higher order serial correlation in the residuals. This is further supported by the result of the Hansen test for over identification that validates the instruments employed.

Table 1
Descriptive analysis of the variables.

Variables	Mean	Standard Deviation
Lagged GDP per capital	9.564	1.6765
Electricity	1.987	6.766
FD	3.376	10.543
Agric	3.877	14.765
Log of Foreign Aid	4.099	19.098
Trade	0.897	25.988
Inflation	6.099	34.211
Government	65.098	34.991
Labour	13.955	32.907
Governance Effectiveness	7.345	13.2345
Life Expectancy	3.2381	13.9825
Fertility rate	4.9872	7.3994
Primary School	2.8977	4.9954
FDI	18.789	1.899
Portfolio Investment	1.3221	0.5433
Saving rate	3.876	13.988

Table 2
The effect of electricity generation on economic growth.

Variables	(1) OLS	(2) Fixed Effect	(3) SYSGMM1	(4) SYSGMM2	(5) SYSGMM3
Lagged GDP per capital	−1.131***	−5.429***	−1.649**	−1.0987***	−0.9876***
	(0.173)	(0.565)	(0.466)	(0.178)	(0.029)
Electricity	0.0601***	0.0521***	0.1105**	0.1337***	0.1413***
	(0.021)	(0.031)	(0.004)	().013)	(0.004)
FD	−0.007	−0.0230	0.0006	0.0016	0.0041
	(0.006)	(0.012)	(0.021)	(0.006)	(0.004)
Agric	−0.0161	0.889	0.1336**	0.05610**	−0.0412***
	(0.022)	(0.058)	(0.040)	(0.031)	(0.005)
Log of Foreign Aid	0.1306	0.1206	−0.7289**	−0.1081	−0.2289***
	(0.113)	(0.167)	(0.371)	(0.210)	(0.031)
Trade	0.0156***	0.0090**	0.0441***	0.0433	0.0233***
	(0.003)	(0.005)	(0.006)	(0.007)	(0.003)
Inflation	−0.0015***	−0.0012***	−0.0015	−0.001***	−0.002***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Government	−0.0062**	−0.0089**	−0.2571**	−0.1768**	−0.1667***
	(0.002)	(0.041)	(0.081)	(0.0087)	(0.0016)
Labour	−3.987***	1.8971	5.8719***	4.4409***	−1.9118***
	(0.453)	(1.322)	(0.861)	(0.544)	(0.564)
Governance Effectiveness	0.0143***	0.0081**	0.0423***	0.0455**	0.0433***
	(0.002)	(0.005)	(0.007)	(0.006)	(0.004)
Life Expectancy	0.1388	0.1206	0.1564***	0.0761***	0.0676**
	(0.124)	(0.154)	(0.023)	(0.0843)	(0.011)
Fertility rate	0.0322	−0.1655	−0.5912	−0.1899*	0.0424*
	(0.1990)	(0.1022)	(0.0004)	(0.0766)	(0.056)
Primary School	0.1122***	0.0123***	0.1156***	0.0012***	0.0054***
	(0.004)	(0.0004)	(0.0001)	(0.0003)	(0.0051)
FDI	0.1881***	0.1141**	0.2301***	0.3211***	0.4533**
	(0.0151)	(0.012)	(0.081)	(0.004)	(0.000)
Portfolio Investment	0.3231***	0.866**	0.7655***	0.5641***	0.3341***
	(0.0023)	(0.0051)	(0.001)	(0.003)	(0.000)
Saving rate	0.5776***	0.8761***	0.7762**	0.6771***	0.4339***
	(0.001)	(0.003)	(0.004)	(0.0002)	(0.0001)
Intercept	11.078**	33.035***			
	(3.568)	(7.713)			
AR (2) test			−2.6110	−1.5390	−1.5300
			[0.103]	[0.133]	[0.129]
Hansen test			34.009	33.281	65.7230
			[1.000]	[1.000]	[1.000]

Notes: standard errors are in parentheses; ρ-values in brackets; ***; **; * represents 1%; 5% and 10% significance levels respectively.

On other explanation variables, the results as obtained from their coefficients are consistent with economic theory and other existing empirical literature. For instance, the coefficient of FDI is positive and statistically significant, implying that FDI induces significant influence on growth. This is on line with the finding of existing studies like Fondja [38]; Gozgor et al. [36]; Adedoyin Isola Lawal et al. [26]. Trade openness impact on growth is positive and significant, suggesting that market liberalization policies that promotes international trade advances economic growth in the studied economies. This result is in line with the findings of Lawal, Somoye, Babajide and Nwanji [89] and Lawal et al. [26]. The results on financial development (FD) shows that a positive relationship exist between FD and growth, suggesting that improvement in the financial sector will spur growth and advance electricity consumption. Our result is in line with [14]. The result of the coefficients of each of agriculture and labour is positive and significant, implying that each of these variables stimulates growth. This empirical evidence is in line with existing empirical studies for instance Ref. [42] established a positive relationship between electricity and growth [25,73,89,90]; documented existence of a positive relationship between growth and agriculture [88], observed existence of a positive and significant relationship between FDI and economic growth.

On inflation, the result shows that a negative relationship exist between inflation and economic growth. This is in line with economic theory as inflation bring uncertainty and panic into the system, thereby distorting growth (see also [4]. Like inflation, the relationship between aid and economic growth is negative and significant. This relationship could be what [88,91] described as Dutch disease effect on exchange rates volatility. The relationship between government spending and growth is negative, this could point to the fact unproductive spending characterized by big government with over bloated civil services and overheads could alter growth. This result is in line with findings of [27,92,93].

To establish the validity of our specification, we conducted robustness check as presented in column (4) of Table 2. From the results, it can be deduced that the effect of electricity on economic growth remains positive and significant, with little or no change to the signs and significance levels of most of the other control variables. The AR (2) test result support the existence of no significance second-order serial correlation in the first-differenced residuals and the results of the Hansen statistics test support the validity of instrument used.

3.2. Threshold effect

The previous section focused on the link between energy consumption and economic growth within the confines of the assumption of linearity, which suggest that the absolute effect of energy consumption on growth in both intense and even periods are the same (i.e. symmetrical). As noted by Refs. [32,45,46,50,53], under an asymmetric situation where energy intensity is high, the effect of energy consumption on economic growth will vary across intense and even periods. To account for this, the current study employed a dynamic panel threshold method that calibrates a non-linear hypothesis into its framework. The results of our analysis are reputed in Table 3. From the results, it can be deduced that the estimated threshold value for energy intensity based on two stage least squares techniques is 0.48, the lower limit of threshold value is 0.38, while the upper limit is 1.64 based on 95% confidence level. The coefficient of $\widehat{\beta}_1$ and $\widehat{\beta}_2$ are 0.542 and $-$ 0.344 respectively. These values imply that, there is a positive marginal effect on economic growth via energy consumption per capita, in the period characterized with low energy intensity with reverse marginal effect with negative consequence when faced with high energy intensity. On other variables, the relationship as experienced in the results obtained confirms with a priori expectation. For instance, positive relationship is noted to exist between economic growth and each of FDI, Agric, trade, labour and government spending. The implication is that, an increase in each of these variables will induce an upward surge in economic growth. The result further reveals that a negative relationship exists between each of inflation, aid and growth. This inverse relationship suggests that a reduction inflation rate will impact positively on growth.

The results of the socio-cultural and political factors also show that significant and positive relationship exist between economic growth and each of governance effectiveness, life expectance and primary school enrollment rates. The result of the relationship between governance effectiveness and growth suggests that the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies play key role in shaping the direction and growth rate of the economy of the studied African economies. This result is in line with the findings of [54,55]. The result on the relationship between growth and fertility rate is negative but not significant. This suggest that though an inverse relationship exist between growth and fertility rate as chances is that potential productive resources are diverted into childbearing activities, thus, slowing down growth, the impact of this is insignificant.

We further subject our analysis to uncertainty as presented in Table 4. From the results obtained, it is evidence that the coefficients of energy intensity; the lower and upper limits of threshold values at 95% confidence level remains at 0.48, 0.39 and -1.64 respectively. The implication is that, uncertainty does not impact on the threshold of energy intensity [32,47]. However, significant changes are noted in the regime $-$ dependent

Table 3
Economic growth and energy consumption.

Estimated threshold value $\left(\frac{tpes}{Y}\right)$	
$\widehat{\gamma}$	0.48***
95% confidence interval	[0.39$-$1.64]
Impact of energy consumption on per capita (*dec*)	
$\widehat{\beta_1}$	0.542***
	(0.191)
$\widehat{\beta_2}$	$-$0.341***
	(0.100)
Impact of control variables	
Lagged GDP per capital	$-$18.987***
	(4.980)
Electricity	0.544**
	(0.055)
FD	0.655***
	(0.008)
Agric	0.4332**
	(0.0098)
Log of Foreign Aid	4.098***
	(0.8711)
Trade	3.433***
	(0.455***)
Inflation	$-$3.221***
	(0.1222)
Government	3.988**
	(0.0011)
Labour	2.223***
	(0.3321)
Governance Effectiveness	2.487***
	(0.0456)
Life Expectancy	1.7661***
	(0.0004)
Fertility rate	1.0365
	(0.025)
Primary School	3.1942**
	(0.0023)
FDI	2.098***
	(0.1145)
Portfolio Investment	4.231***
	(0.0991)
Saving rate	3.1226***
	(0.003)
Numbers of economies	17

Table 4
Economic growth and energy consumption including energy prices among the explanatory variables.

Estimated threshold value $\left(\frac{tpes}{Y}\right)$	
$\widehat{\gamma}$	0.48***
95% confidence interval	[0.39−1.64]
Impact of energy consumption per capita (*dec*)	
$\widehat{\beta_1}$	0.432**
	(0.301)
$\widehat{\beta_2}$	0.314***
	(0.101)

coefficients such that $\widehat{\beta}_1$ and $\widehat{\beta}_2$ equal 0.432 and −0.314 respectively under the condition of uncertainty. These results suggest that stronger effect from economic growth on energy consumption exists under uncertainty condition.

The results of the estimated threshold value at 48% have some critical policy implications. First it implies that the intensity level of energy is key to analyzing the impact of energy consumption on growth. Second, it suggests that a nonlinear relationship exist between economic growth and electricity consumption in the studied economies. Third, and most important, the coefficient of the estimated threshold regressor model at 0.48, suggests that threshold energy intensity/value is at 48%, below which electricity consumption impacts on growth positively; and beyond which electricity consumption deters/impedes on growth. It is therefore recommended for policy makers to ensure that electricity intensity is kept below the threshold level for the studied economies. This implies that in order to drive growth, attention should not just be on increasing access to electricity, but in enhancing energy efficiency in electricity sub-sector. Energy efficiency in the studied economies can be achieved by efficiency and effectively deploying energy saver appliances in the production process, prevent energy thefts, energy lost among others [46–48].

4. Conclusion

Over the years, African economies have attempted to increase their energy base, knowing fully that energy is a vital requirement for growth. Electric energy plays vital role in energy bank globally, as it significantly contributes to achieving sustainable economic growth and development. When making energy policy, it is very important to have a good understanding of the linkages between energy consumption and economic growth, so that policy framework will be able to effectively aid sustainable growth. As earlier stated, the relationship between energy and economic growth could be in four possible directions: energy-led growth following; growth-led energy following; feedback/bi-directional; and neutrality/indifference hypotheses. Each of these directions have unique implication for policy making. Besides examining the direction of the causality between energy and economic growth, energy efficiency in the act of production is key to achieving sustainable growth. With efficient use of energy, more goods and services will be produced, the effect of energy utilization on climate is reduced, among others.

This study examined the relationship between economic growth and electricity consumption in the sub-Sahara Africa economies for the period from 1971 to 2017. The study also calibrated the impact of some salient control variables like FDI, agricultural output, trade, government expenditure and inflation among others. Noting the possibility that electricity consumption and other control variables employed in of model could be jointly determined with GDP growth, this study employed system GMM estimator techniques to examine the nature of the relationship between these constructs. The system GMM have the capacity to deal with endogeneity related issues. It is important to state that, when faced with the possibility of data being susceptible to measurement error, the system GMM longer lags of regressors can effectively address this challenge. To validate the orthogonality assumptions that surrounds the system GMM estimates, we employed the Hansen test of over identification, the Arellano & Bond [60] test of second −order serial correlation, and the [82] small sample correction of the standard errors in all two-step system GMM estimations.

Our baseline results and results from a series of robustness checks showcase existence of a positive and significant relationship between electricity consumption and economic growth. The results clearly state that electricity promotes economic growth, supporting the energy-led growth following hypothesis, thus, policies that stimulate electricity consumption should be promoted. The results of the other explanatory variables also suggest that FDI, agriculture, governance efficiency, primary education, trade and labour stimulates growth. Thus, it is essential for government to put in place policies that will increase agricultural output, enhance trade, increase human capital development and governance effectiveness among others. However, the result of the relationship between economic growth and inflation was negative. This inverse relationship has some policy implications, for instance, to promote sustainable growth, economic managers show lower inflation rate in the studied economies. The second leg of our analysis focuses on the impact of energy intensity on economic growth. Here, we intend to know, whether the effect of energy consumption on growth is influenced by the level of energy intensity. To do this, we employed an advanced dynamic panel threshold regression estimates with a focus on examining whether there exists a threshold energy intensity level in the asymmetrical effect of energy consumption on economic growth. Our result shows that the intensity level of electricity is a major factor in explaining the impact of electricity consumption on growth. The study further observed that 48% is supportive to growth while any threshold beyond 48% will have a negative impact on growth. The threshold component of our analysis suggest that a bi-directional relationship exist between economic growth and electricity consumption, this suggest that economic growth and electricity consumption are mutually dependent, thus, policy directions should be towards promoting electricity consumption on the one hand, and sustainable growth on the other hand. The result also suggests a caution on adopting electricity/energy conservation policy, as this may have negative consequences on the economic growth of these countries.

The results of the estimated threshold value at 48%, which represent the level of energy intensity on growth (above which electricity consumption will impact on growth negatively, while electricity consumption below this level will stimulate growth) offers some key policy implications: (i) policy makers should ensure that electricity consumption is not beyond the threshold value, this can be achieved through the use of energy saving appliances; addressing issues relating to energy theft and loss; (ii). It has been established that a feedback mechanism exist between electricity consumption and economic growth in the studied economies, and that electricity consumption beyond the threshold of 48% will deter economic growth, it is therefore suffice that rather than increasing electricity consumption beyond this threshold, policy direction should be towards stimulating growth by investing in agriculture, education, health, trade and other macroeconomic variables that have positive relationship with growth, once electricity consumption of 48% threshold is attained.

We further calibrated uncertainty into our model to know whether changes resulting from fluctuations in electricity prices will alter our results. Our findings revealed that uncertainty has little or no effect on threshold value of energy intensity. The study therefore suggests that policy makers should keep energy intensity below the threshold level in transition economics to enhance sustainable economic growth. In other words, in order to sustain economic growth, the studied economics should pursue policies like decreasing their energy intensity in production and consumption reduce energy loss and theft by effectively and efficiently deploying energy use.

Though the current study has contributed to the body of knowledge on the relationship between electricity consumption and economic growth, there is need for further study in order to improve the current state of knowledge on the subject matter. Thus, we suggest that further study could investigate the impact of renewable electricity sources on economic growth in Africa. Furthermore, the current study employed aggregate data set, future research could focus on employing disaggregated data set. Different methodology can also be employed to examine this link.

CRediT authorship contribution statement

Adedoyin Isola Lawal: Conceptualization, Methodology, Software. **Ilhan Ozturk:** Supervision, Writing - review & editing. **Ifedolapo O. Olanipekun:** Data curation, Writing - original draft. **Abiola John Asaleye:** Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

System GMM: System Generalized Methods of Moments
GDP: Gross Domestic Products
P-ARDL: Panel Autoregressive Distributed Lag
PQR: Panel Quantile Regression
OECD: Organisation for Economic Co-operation and Development
R&D: Research and Development
DCCE: Dynamic Common Correlated Estimator
VECM: Vector Error Correction Model
USDA: United State Department of Agriculture
AR(2) test: Autoregression (2) test