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Electricity consumption and economic growth: Evidence from the East African community

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ABSTRACT

This study investigates the dynamic causal relationship between electricity consumption and economic growth in the East African Community (1990–2021). It seeks to interrogate the nature of relationship between electricity consumption and economic growth. The hypothesis used in this study is four folded including growth, conservation, feedback and neutral hypothesis.

It uses panel data estimation techniques, particularly the panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and non-linear autoregressive distributed lag (NARDL). The panel augmented Dickey Fuller (ADF)-fisher and Levin, Lin & Chu (LLC), 2003, was used to test the unit root process. Dumitreschu-Hurlin (2012) and pairwise Granger tests were used to test for the direction of causality.

The findings indicate growth hypothesis with a unidirectional relationship running from electricity consumption to economic growth. Regional governments must increase their investments in electricity market trading to boost economic growth. Greater benefits from regional cooperation can be realized with increased investment in electricity consumption.

This is a novel study of the dynamic causal relationship between electricity consumption and economic growth in the East African Community. It is a ground-breaking inquiry into the possibility of integrating electricity markets and their role in promoting economic growth.

1. Introduction

Electricity is an important enabler of economic growth and supports most productive industrial activities [1,2]. In fact many scholars contend with the view that a direction of causality exists between electricity consumption and economic growth [1,2,3]. Especially in low-income countries that are yearning to grow rapidly, it opens up several socioeconomic activities, such as creating employment opportunities, improving the living standards of most households; increasing commerce and trade; agricultural production, and transport.

To attain and sustain high rates of economic growth (GDP), high rates of electricity consumption must be achieved [4]. A change in one variable affects the other, what remains key is to establish causality between these variables. The key variable of causation becomes the targeted policy variable that policy planners would manipulate to achieve optimal growth and macroeconomic stability. Studies on the direction of causality between electricity consumption and economic growth have spurred a controversial debate [4,5].

In our hands is both a contentious and polemic argument arising due to differences in methodology, countries, time periods, and data sets used [6]. Therefore, it is in the best interest to carry out this study to resolve the contradicting evidence in literature.

Global economic growth increased by an average rate of 3.1 percent over the period of 1990–2021. While that of Sub Saharan Africa grew by 2.7 percent over the same period [7] Global Electricity Consumption has been growing at an average rate of 2 percent from 2000 to 2018. While in 2019, it declined by 0.4 percent, while in 2020 it declined by 4 percent, mainly due to COVID-19 and the effects of lockdowns that was associated with the COVID-19 pandemic, this halted a lot of consumption and even production [8].

East Africa's electricity markets face several challenges such as rampant load shedding, old grid infrastructure, insufficient investment in grid extension [9,10]. With the revitalization of the East African Community market, there is a need for greater cooperation and integration of energy markets in the region to foster economic growth and sustainable development [11]. Electricity consumption can serve as a

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hub for rapid economic growth and sustainable development. It is important to ascertain the electricity–growth nexus in this region.

The main purpose of this study is to establish a dynamic causal relationship between electricity consumption and economic growth in five selected countries in the East African community (E.A-5). It uses a multivariate framework to contribute to the theory of the methods. The use of fully modified ordinary least squares and dynamic ordinary least squares has some useful implications in establishing causation between the electricity-growth nexus.

More specifically, the objectives of this paper is to investigate the direction of causality between electricity consumption and economic growth in East Africa (1990–2021). Secondly to analyse this relationship using various econometric techniques. Finally to inform policymakers on how electricity consumption can be leveraged for economic growth in the region.

The dynamic causal relationship between electricity consumption and GDP is based on the following four arguments: growth, conservation, feedback, and neutrality.

(i) The growth hypothesis argues that electricity consumption has unidirectional causality to GDP. This hypothesis is valid if there is a long-run equilibrium between electricity consumption and economic GDP. This is reinforced by studies [12,13,14,15,16,17, 18,and18]. Under the growth hypothesis, electricity-saving strategies may have a negative effect on GDP, whereas policies promoting electricity consumption will lead to GDP growth.
(ii) The conservation hypothesis claims that electricity-saving strategies may not have a significant negative effect on GDP. The conservation hypothesis is confirmed if unidirectional causality exists from economic growth to electricity consumption. Here policies of energy efficiency can be undertaken with no major setback The feedback hypothesis exhibits a two-way causal relationship between electricity consumption and economic growth [2,3,19–23].
(iii) Third, the feedback hypothesis emphasizes the interdependent relationship between electricity consumption and economic growth and their complementarity as [24,25].

(iv) Finally, the neutrality hypothesis reflects electricity consumption as a minute contributor to the economy's overall output with negligible or no effect on GDP [26].

The main contribution of this study to the energy economics literature is the use of a multivariate framework to analyse a causal relationship in this panel [27]. Therefore, this study assembled the relevant variables carefully to avoid omitted variables bias. The main variables in this study are electricity consumption and economic growth, while trade openness, electricity trade, gross capital formation and total labour force are controls for the model.

Second, its contribution to the theoretical literature includes the extension of the neoclassical aggregate production function, which adopted capital and labour that have been restored in our model as controls [2,28–30]. It adopted the Solow growth model, where capital and labour are complementary inputs to electricity. Capital investment increases the stock of outputs, while total labourforce through employment of both skilled and unskilled workers augment aggregate output, thereby promoting growth [31]. Therefore, it expands upon the neoclassical production function by including electricity consumption as a key input in the aggregate production function.

Neoclassical endogenous growth has formed a strong building block in our model theoretic. Electricity consumption is a key input without which production can hardly proceed [32,33]. In this study, electricity consumption was used as a proxy for measuring energy consumption. The inclusion of electricity trade is intentional to deduce the value of improving the regional market pool in East Africa. This has not been handled by earlier studies and is a pillar that this paper is adding to the theoretical literature.

Third, we used panel data econometrics to investigate a panel of five East African countries (EA-5). The adoption of panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and nonlinear autoregressive distributed lag (NARDL) for the interpretation of these results is robust in solving the cross-sectional dependence problem. This is a yardstick to augment econometric theory. These models are superior in analysing the unobserved heterogeneity problem. They yield satisfactory results with interpretations that have useful implications for a causal relationship between electricity consumption and economic growth nexus [6].

Stationarity tests were performed based on the current literature. The panel augmented Dickey Fuller (ADF)-fisher and Levin, Lin & Chu (LLC), 2003 was used to establish the unit root process. A test for stationarity determines whether a variable in a time series is non-stationary, meaning that the mean and variance change over time. Non-stationary time series can lead to spurious regression results, and combining the three stationarity tests gives greater validity to the results obtained. The choice of LLC is based on the assumptions of the same first-order autoregression, which is fulfilled in this study [34]. The panel Kao (Engel- Granger), Johansen Fisher, and Pedroni co-integration tests were used to examine the long-run relationship among variables. These tests are superior because they overcome the endogeneity problems that maybe prevalent in the model.

Finally, based on the current literature, few studies have been conducted on selected countries of East Africa, namely Kenya, Tanzania, Uganda, Rwanda, and Burundi. South Sudan was a newly formed member whose data were excluded from this study. These are members of a regional market that is forging an economic integration, so this study is useful for guiding regional economic policy dialogue.

The remainder of this paper discusses electricity consumption and economic growth in East Africa in Section 2. The empirical framework is ladened with literature reviews in Section 3, methods in Section 4, findings and discussion in Section 5, and conclusions and recommendations are presented in Section 6.

2. Electricity consumption mix in the East Africa community

East Africa is still in the formative stage of reconstituting its regional market with a fragile political, socio-cultural, and geographical structure. With a population of over 167.98 million people (World Bank, 2017). These interactions are useful for electricity consumption and economic growth. This region faces the challenge of low electricity uptake, owing to limited electricity access and poor grid infrastructure [35,36].

The low-income status and low electricity infrastructure investment must be addressed in the development agenda [37]. The general energy poverty at household level is an issue that many energy economists in the developing world are grappling with [38]. Expanding the electricity foot print across all communities in the region can overcome this barrier, increase output and bring about economic growth. This will achieve both the required transition and security of energy supply. Though electricity consumption for economic growth still supersedes at it has more linkages to all the above. This study has been deliberate to focus on the electricity consumption and economic growth nexus.

Following the sustainable development goal (SDG) 7 of affordable, reliable, clean, sustainable modern energy for all, electricity consumption can foster an economic growth rate relevant to achieving this objective [38]. East Africa is abundantly endowed with energy resources, although most have not been harnessed for commercial development. The electricity subsector is growing by 7.1 % per year, while real GDP is growing by 4.6 % per year, as shown in Table 1 [39].

With a vast amount of investment in energy infrastructure and consumption, over U.S $ 5.8 billion in aid has been committed to developing geothermal and wind energy potential in the region. With hope that electricity generation will boost electricity consumption,

Table 1
Electricity statistics for Selected East Africa Countries.

Country	Pop (mill)[b]	Elec Gen (MW)	Electrification (%)	Cost Grid Con (US$)	Elec Cons (GWh)	Price (Dom US$)	Real GDP growth rate[b]
Burundi	10.5[b]	41	10	250	300	0.37	0.0
Kenya	48.5[b]	2712	75	400	9500	0.23	5.0
Rwanda	11.92[b]	211	30	350	500	0.20	6.2
Tanzania	55.57[b]	1583	37	397	11,000	0.18	7.1
Uganda[a]	41.7[b]	1350[a]	28	725	3250	0.19	4.8
Average	33.56	1075.6	36	424	4910	0.234	4.62

[a] ERA 2021.
[b] World Bank (2017).
Source: Adapted from IEA (2017)

which would in turn lead to rapid economic growth and sustainable development in the long run [39].

East Africa can emerge as a clean energy leader in sub-Saharan Africa (SSA), when it pursues the renewable energy goals more purposefully and ambitiously [40]. This must be backed by deliberate efforts to overhaul and purposefully develop its energy sector with an energy market pool. This is a potential driver of economic growth in the region.

The major problems are the weak and aging grid system and the inter boundary connections. *Trans*-boundary cooperation is yet to be fully realized, and there is a shortage in the interconnection infrastructure needed in the trade of energy resources and power across the borders of net power exporters and net power importers. Cooperation and good governance must be embraced within the existing institutional and regulatory frameworks to boost economic growth.

East Africa has a number of bilateral power agreements, the oldest of which is Uganda and Kenya set up in 1955 with a 132 KV with a current supply capacity of 300 MW to be expanded to 500 MW by 2025, a 110 KV mini-power pool among the Democratic Republic of Congo- Rwanda-Burundi, managed by SINELAC, a 330/440 KV for Zambia-Tanzania-Kenya- Ethiopia signed in 2014, Rwanda – Tanzania with a supply capacity of 200 MW to be expanded to 1100 MW. 30–220 KV Rwanda-Uganda, 400 KV Uganda- Rwanda, and Kenya signed in 2014.

Despite this effort, trading in electricity markets is still at a low level. Yet some countries in the East African community have a surplus while others have a deficit of electricity generated. A systematic inquiry must be undertaken to inform rational decision making regarding the electricity growth nexus within the East African community.

The electricity generation mix varies from country to country, as indicated in Figs. 1–5. This variation has useful implications for economic growth and policymaking in terms of energy market pool and cooperation. The EAC can forge a better energy infrastructure to enhance the energy market, in which electricity becomes a tradable commodity. The increased fungibility of electricity as a strategic commodity within the region can be a hub for rapid economic growth and sustainable development [41].

The electricity generation mix has variations that are useful to the energy market pool. Kenya has the most diversified generation mix, whereas Burundi is the least diversified. Although all countries have made efforts to develop their hydroelectricity, there are still prospects for *trans*-boundary trading in energy to promote economic growth.

The power market allows sale of power from low-cost to high cost market to allow efficient utilization. This accelerates power uptake and economic growth. The East African Electricity market integration has made efforts through the East African Power Pool (EAPP), which began in 2012, aiming at the interconnection between power grids across boundaries with Uganda, Ethiopia, Kenya, Tanzania, Rwanda, the Democratic Republic (DR) of Congo, and South Sudan. Members of the East African Community (EAC) include Burundi, Rwanda, Kenya, Tanzania, Uganda, and South Sudan. However, interregional trade is approximately 8.3 %, which is still lower than the continental average of 14.5 % [33].

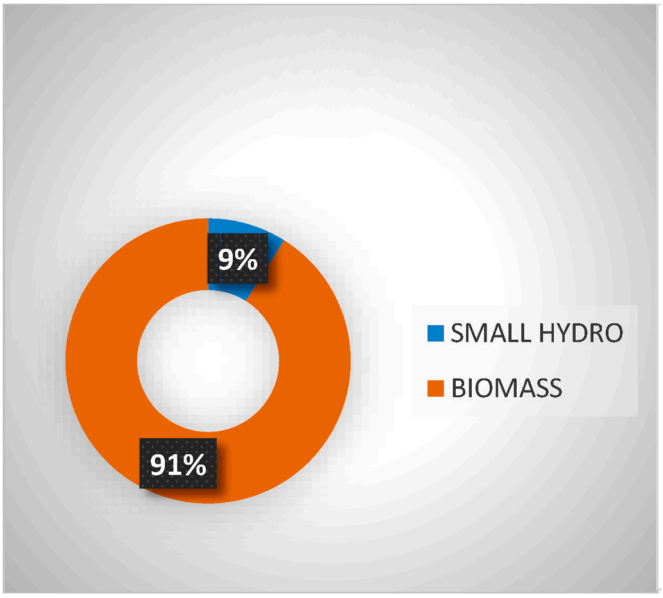

Fig. 1. Electricity generation mix For East Africa Countries. BURUNDI'S ELECTRICITY GENERATION MIX.
Source: Adapted from Ref. [33] Pg. 20–41.

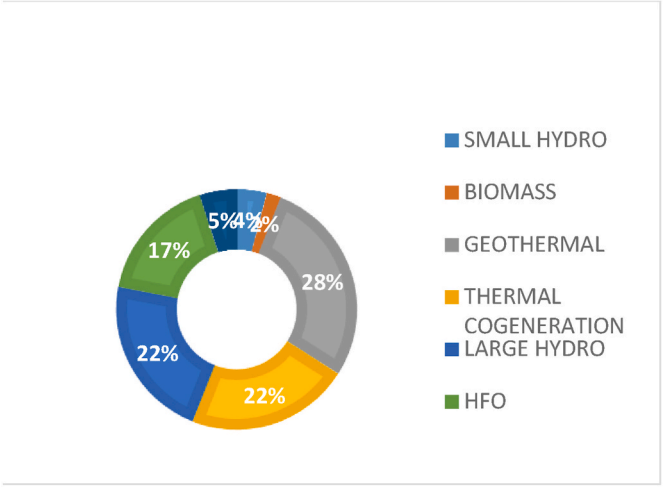

Fig. 2. Electricity generation mix For East Africa Countries. KENYA'S ELECTRICITY GENERATION MIX.
Source: Adapted from Ref. [33] Pg. 20–41.

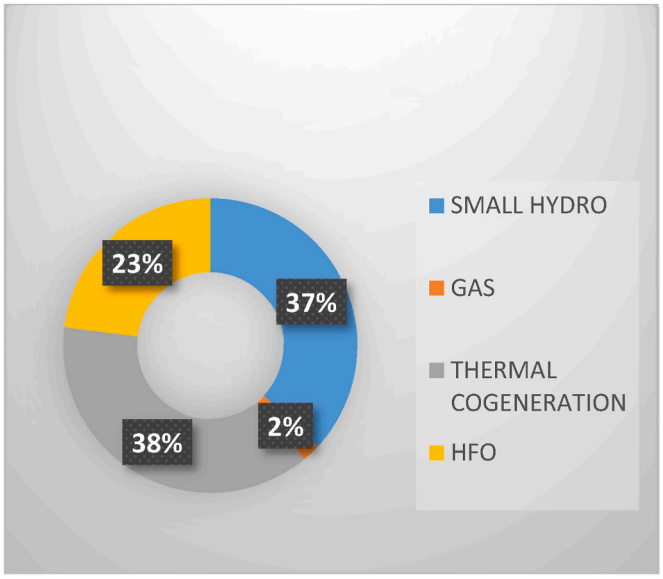

Fig. 3. Electricity generation mix For East Africa Countries. RWANDA'S ELECTRICITY GENERATION MIX.
Source: Adapted from Ref. [33] Pg. 20–41.

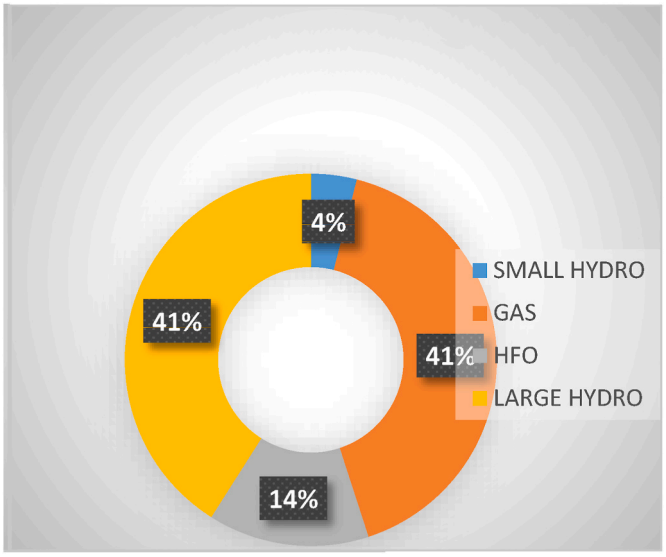

Fig. 4. Electricity generation mix For East Africa Countries. TANZANIA'S ELECTRICITY GENERATION MIX.
Source: Adapted from Ref. [33] Pg. 20–41.

3. Empirical framework

Earlier work on this subject [42–45] offset a polemic debate in contemporary literature and clarified the central thesis [41]. This has remained contentious, and hence the need for further inquiry [2]. The rest of the polemic arguments fall into four hypotheses. For instance the bi directional causality (feedback) hypothesis has been supported by the following studies [46,47]: who studied Japan [48,49], studied Brazil [49,50], studied Taiwan [50], for Greece [51], for South Korea [52], for Argentina) [53] for Philippines and Canada) [54] studied Malawi [55, 56], for Taiwan [57], for Canada and UK [57], for G7 [58–61], for Pakistan [4,5,3], for Uganda [62,63], for U.S.A [64,65,66], [67], Others that used panel data studies with same results include [52,57],75,[68], [69] for OECDs [70,71], for OECD [72], for 26 OECD, [71,73,74] for 13 Eurasian countries, [397] for 25 OECDs [69,75,76], for Central American countries [77], looked at Romania while [78] looked at the entire globe [79,80,81]. for 11 OECD countries [82], for 18 Latin American countries [83], for G7 [84], for GCC [85], for China [86,87], for BRICS [88], for 72 countries [89], for the Balkans [90], for 12 EUs, and [91] for CIS countries.

The growth hypothesis argues that a unidirectional relationship exists between electricity consumption and economic growth. It has been supported by the following studies: [12,66,92–101]. The conservation hypothesis is supported by previous studies [22,102],[91,103], [104–108]. The neutrality hypothesis is supported by several studies [46,109,110,111–113].

[114] examined Vietnam using data from 1971 to 2001, and the findings support energy-led growth [115]. examined Cameroon using the generalized method of moments (GMM), which supports energy-led growth [100]. used data for Nigeria between 1971 and 2014 using both dynamic modified and fully modified ordinary least squares (DMOLS and FMOLS), cointegration, Toda-Yamamota, and Mwald tests, and found a relationship between energy consumption and GDP [116]. used data from 1980 to 2008 using VECM and found a feedback hypothesis [117,118]. studied South Africa using data from 1971 to 2012, and used an ARDL and CD production function and found no causality [119]. studied Taiwan's economy using data from 1984 to 2014 to determine the feedback hypothesis.

[120] studied Egypt using VECM found Electricity led growth [121]. looked Malaysia using ARDL found a relationship running from electricity consumption to GDP [122,and132]]. investigated Denmark using data of 1970–2012, he used ARDL and Granger causality test and found no relationship between electricity and GDP, in addition [123] used cumulative sum of squares, and adopted the Solow growth model [124]. studied Nepal using data of 1975–2014, they ARDL, Toda Yamamoto and granger causality test they found no relationship, earlier [125] had studied the same and found a unidirectional relationship running from electricity to economic growth [65]) studied Turkey using ARDL, Toda Yamamoto and Granger, support a feedback hypothesis.

[65] Studied Qatar using ARDL, Toda Yamamoto supported a feedback hypothesis [126]. studied electricity consumption and GDP in Pakistan using data from 1960 to-2014, they used a VECM to support electricity-led growth [127]. studied China and found a relationship running from GDP to Electricity, while [128] Toda Yamamoto and Granger support a growth hypothesis.

A summary of the literature that associates electricity consumption and economic growth in African countries is shown in Table 2. The dominant result is the growth hypothesis, which is in favour of policies that would expand investment in the electricity sector to foster rapid economic growth.

3.1. Meaning of notations

3.1.1. A/no – author reference number

→, 2, and ≠represent unidirectional causality, bidirectional causality, and no causality, respectively; AGR- Agriculture, BEC Biomass Energy Consumption, BOP Brent Oil Price, CEC Commercial Energy Consumption, CEU Commercial Energy Use, CLEC Clean Energy Consumption, Com Commercial, CO2 carbon dioxide emissions, CPI Consumer Price Index, E Energy, EF Ecological footprint, ELC Electricity, Emp Employment, EP Energy price, FD Financial Development, FDI Foreign Direct Investments, Govexe Government Expenditure, Ind Industrial Energy, K gross Capital, L total labourforce.

Methods: ADF Augmented Dickey Fuller, ARDL Autoregressive distributed lag, DOLS dynamic ordinary least square, ECM Error correction model, FE Fixed Effects, FMOLS fully modified Ordinary Least squares, GMM, Generalized mean Method; IPS IM Pesaran & Shun LLC Levin Lin and Chu PECM Panel Error Correction Model, PDT Panel data techniques, POLS Panel Ordinary Least Squares, PP Phillip Peron, PRT

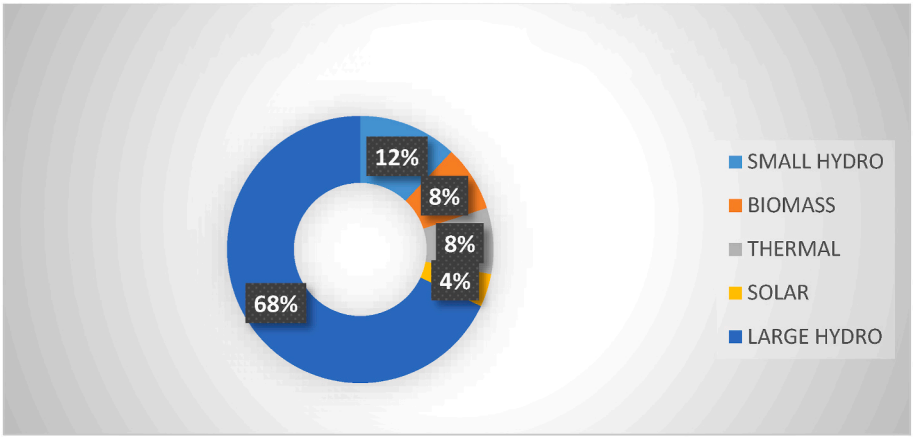

Fig. 5. Electricity generation mix For East Africa Countries. UGANDA'S ELECTRICTY GENERATION MIX.
Source: Adapted from Ref. [33] Pg. 20–41.

Panel regression techniques, VAR Vector Autregression, VECM Vector error regression model TY Toda Yamamota.

4. Methods

Data source was annual data were taken from the World Bank Development Indicators (WDI, 2022) for per capita GDP, trade openness, gross capital formation, total labourforce, and real electricity trade, while additional data on electricity consumption were from international energy agencies (IEA, 2022). Five East African Countries; Burundi, Kenya, Rwanda, Tanzania and Uganda, were compiled for the years 1990–2021, the dataset is large enough to increase the size and explanatory power of unit roots and panel co-integration techniques.

The research was mainly quantitative and used a causal relationship research design. The sampling was purposive by taking on data points for which all data was available. Data was analysed using e-views software.

This study incorporated the neoclassical aggregate production function based on [235,236]. The Solow Growth Model examines the relationship between electricity consumption and economic growth. This study provides electricity consumption as a standalone input into the production model and analyses its relationship with growth. Per capita Gross Domestic Product (PGDP), gross labour force (LBR), gross capital formation (GCF), electricity consumption (ELC), trade openness (OPN), and Real Electricity trade (ELT), the model is specified as:

$$PGDP_t = \alpha + \delta_t + \beta_1 ELC_t + \beta_2 GCF_t + \beta_3 LBR_t + \beta_4 OPN_{t+} \beta_5 ELT_t + u_t \quad 1$$

Where: $PGDP_t$ is output/real GDP per capita.

The parameters α and δ allow for the possibility -specific fixed effects and deterministic trend effects respectively,

ELC_t is Electricity net Consumption,

GCF_t is Gross Capital formation,

LBR_t is total labour force,

OPN_t is trade openness,

ELT_t is Real Electricity trade and

u_t is the error term.

The variables were log transformed as a way to normalise the macroeconomic data

$$LPGDP_t = \alpha + \delta_t + \beta_1 LELC_t + \beta_2 LGCF_t + \beta_3 LLBR_t + \beta_4 LOPN_{+}\beta 5LELT + u_t \quad 2$$

More growth theories postulate that energy is a key driver and that technological development may only boost additional energy consumption [102,237].

The choice of a neoclassical production framework in general, and the Solow model in particular, is essential as a building block for a multivariate framework. The Solow model parcels out capital and labour as the key inputs in the production function. This is useful in explaining how economic growth takes place. This study further adopts electricity consumption as an input variable in the aggregate production function [3,236]. Electricity consumption augments both capital and total labour force in the production process. Therefore, this is an improvement since production is complete with the use of the three inputs, Gross capital K, total labour force L, and Electricity, E.

The choice of control variables of capital and labour are traditional inputs in the Solow growth model, while trade is a traditional macroeconomic variable, this study has extended it to electricity trade and trade openness that are supported by neoclassical growth theory in specifying the model.

Economic growth is a matrix of goods and services that an economy can produce. It is best represented by the production function. The basic inputs are capital, labour, and the composite energy good. In this study, we used electricity consumption as a proxy for energy. Capital formation and electricity consumption are studied in the same model because capital is conceptualized as a stock and electricity consumption is a flow of energy resources.

This study uses panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and nonlinear autoregressive distributed lag (NARDL). The choice of these models was mainly due to the presence of the cross-sectional dependence problem in the time series. Furthermore, the non-asymmetric behaviour of some variables within the series. These models address these issues. Variables of study were carefully selected as shown in Table 3, to avoid misspecification a Ramsey RESET (Regression specification error test) was done.

The measurement and expected signs of the selected variables are listed in Table 3. Variables like trade openness (OPN) adapted from standard conventions by adding up total imports and exports divided by GNI, Real Electricity trade (ELT) was conceptualized as total electricity imports added to exports.

The causality test was performed using the Granger and Dumitrescu-Hurlin (2012) test. This was done to identify the direction of the causality between electricity consumption and economic growth.

The Causality test was performed using the Granger and Dumitrescu-Hurlin (2012) test [230]. The justification for running a causality test is to confirm which variable has a greater influence on the other, so that it can be manipulated in decision-making. According to the standard Granger's (1969) test, variable Y is caused by variable E if Y can be associated with Y more strongly from past values of both Y and E than from past values of Y alone.

$$Y_t = \mu + \sum_{j-1}^{n} \gamma Y_{t-j} + \sum_{j-1}^{n} \alpha_1 1E_{t-j} + \mu_t \quad (3)$$

Table 2
A brief outlook of literature on the Energy Economic Growth Nexus for selected African countries.

A/No	Author	Country	Method	Variables	Results
[129]	Arima (1993)	Nigeria (1960–1989)	Granger	E, ELEC, Y	Nigeria,E→ Y
[130]	Arimah (1994)	47 African	Regression	E, Y, Urb, Land, Pop, Agric, SAP, Region	E→ Y (−)
[131]	Ebohon (1996)	Tanzania (1960–1981A) Nigeria (1960–1984A)	Granger	Energy supply; GNP Y	Tanzania E2Y Nigeria E2Y
	Ojjinaka (1998)	Nigeria (1960–1995)	Granger	E, GDP	Nigeria, E → Y
[132]	Jumbe (2004)	Malawi (1970–1999A)	Engle-Granger	ELC;	Malawi, ELC 2Y
[133]	Wolde-Rufael (2004 b)	17 African (1971–2004)	ARDL, TY Mwald, Grangre	TEC, RE, ELC, Y	
[134]	Wolde-Rufael (2005)	18 countries (1971–2001A)	ARDL bounds test; TY	Energy use per capita; real Y per capita	Algeria, Y → E(þ) Benin, E ≠Y Cameroon, E → Y(þ) Congo DR, Y → E(þ) Congo Rep, E ≠Y Egypt, Y → E(þ) Gabon, E 2Y(þ) Ghana, Y → E(þ) Ivory Coast, Y → E(þ) Kenya, E ≠Y Morocco, E → Y (2) Nigeria, E → Y (2) Senegal, E ≠Y South Africa, E ≠Y Sudan, E ≠Y Togo, E ≠Y Tunisia, E ≠Y Zambia, E 2Y (2) Zimbabwe, E ≠Y
	Cattaneo et al. (2006)	18 African countries (1972–2006)	Spatial	E, GDP, FDI, Trade	Nigeria, E → Y
[135]	Wolde-Rufael (2006)		TY	ELC per capita; real Y per Capita	Algeria, ELC ≠Y Benin, ELC → Y (þ) Cameroon, Y → ELC (þ) Congo DR, ELC → Y (þ) Congo, Rep., ELC ≠Y Egypt, ELC 2Y (þ) Gabon, Y → ELC (þ), ELC → Y (2) Ghana, Y → ELC (þ) Kenya, ELC ≠Y Morocco, ELC 2Y (þ) Nigeria, Y → ELC (þ) Senegal, Y → ELC (þ) South Africa, ELC ≠Y Sudan, ELC ≠Y Tunisia, ELC → Y (2) Zambia, Y → ELC (þ) Zimbabwe, Y → ELC (þ)
[136]	Akinlo (2008)	11African countries, (1980–2003A)	ARDL bounds test	CEU; real Y Govexe; CPI	
[137]	Chebbi & Boujelbene (2008)	Tunisia (1971–2004)	IRF	E, Y,	Tunisia, E→Y
	Adeniran (2009)	Nigeria (1980–2006)	Granger	E, Y	Nigeria, E →Y
	Gbadebo& Okonkwo (2009)	Nigeria (1970–2005)	ECM, Engle-Granger	E, ELC,gas, Real GDP, Petrol	Nigeria E≠Y, G≠Y, Pet≠Y
[138]	Odhiambo (2009)	South Africa	Dynamic Granger	ELC, EMP, Y	S. Africa, ELC2Y, EMP→Y
[139]	Wolde-Rufael (2009)	17 African countries (1974–2004)	FMOLS, PECM, ADF, PP, Granger	E (O,G, Coal), Y, K, L	E ≠Y(Cameroon, Kenya), Y→E (Egypt, Ivory coast, Morocco, Nigeria, Senegal, Sudan, Tunisia, Zambia), E → Y (Algeria, Benin, S. Africa) E2Y (Gabon, Ghana, Togo, Zimbabwe)
[140]	Ziramba (2009)	South Africa (1965–2006)	TY	E,Y	South Africa, E→Y
	Abbasian et al. (2010)	Algeria (1967–2005)	VAR, Granger, TY	E, Y	Algeria, E ≠Y
	Amirat Bouri (2010)	Algeria (1980–2007)	Engle- Granger	E per capita, Y per capita	Algeria, E→Y
[141]	Chebbi (2010)	Tunisia (1975–2005)	Granger	E, Y, CO2, Agr energy, Ind and Coml Energy	Tunisia, E→Y

(*continued on next page*)

Table 2 (*continued*)

A/No	Author	Country	Method	Variables	Results
[142]	Esso (2010)	7 SSA (1970–2007)	Panel cointegration, PTR, Gregory-Hansen	E, Y	Y→E (Ghana, Nigeria, Cameroon, Ivory coast and South Africa).
[143]	Nondo (2010)	19 COMESA (1985–2007)	PECM,IPS, LLC and Hadri, Panel Granger	E, Y	E 2Y (Burundi, Comoros, Djibouti, Egypt, Eritrea, Ethiopia,Libya, Kenya, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, Sudan, Swaziland, Uganda, Zambia, Zimbabwe).
	Mulegeta et al. (2010)	40 SSA (1980–2007)	Panel cointegration and Causality	E, Y	E→Y
[144]	Odhiambo (2010a)	Tanzania (1971–2006)	ARDL, ECM	E, Y	Tanzania, Y → E
[145]	Ouedraogo (2010)	Burkina Faso (1968–2003)	ARDL, ADF, Granger	ELC, Y	Burkina Faso, ELC ≠Y
[146]	Menya & Wolde-Rufael (2010)	South Africa (1965–2007)	Granger	RE, Y	S.Africa, E→Y
[147]	Ighodaro (2010)	Nigeria (1970–2005)	Granger	E, Y, ELC, Oil and Gas, Health Expenditure, Monetary policy	Nigeria, E→Y
	Vicent (2010)	Nigeria (1980–2009)	VECM, ADF, Granger, PP	E, YK, L	Nigeria, E2Y
[148]	Adebola (2011)	Botswana ((1980–2008)	Bounds test, cointegration, Granger, Zivot Adrews	E, Y, K, L	Botswana, K→ Y
[149]	Adom (2011)	Ghana (1971–2008)	ARDL bounds Cointegration, ADF, PP,	ELC, Y	Ghana, Y→ELC
[150]	Eggoh et al. (2011)	21 Africa (1971–2006)	Panel Cointegration and Causality	E, Y, K. L, EP	Y→E
[151]	Kahsai et al. (2011)	40 SSA (1970–2006)	Panel causality	E, Y, Price Index	E2Y, Y→E
[152]	Al-Mulali et al. (2012)	SSA (1980–2008)	PECM, Panel cointegration	E, Y, CO2, FDI	Y→ E
[153]	Akpan & Akpan (2012)	Nigeria (1970–2008)	Granger	E, Y, CO2	Nigeria, Y→CO2, E→Y
[154]	Al-Mulali & Sab (2012)	SSA (1980–2008)	PECM, Panel cointegration	E, Y, CO2	E →Y
[155]	Al-Mulali et al. (2012)	SSA (1980–2008)	PECM, Panel cointegration	E, Y, CO2, FDI	Y→ E
[156]	Bouoiyour & Selmi (2012)	12 MENA	ADF, Bivariate, PP, Fisher, Panel cointegration and causality	E, Y, ELC, Solar, Gas, Oil	ELC→Y
[157]	Dramani et al. (2012)	Ghana (1970–2010)	VECM, Granger, ADF, PP,	E, Y, ELEC	Ghana, Y→ELC
[158]	Farhani & Rejeb (2012)	15 MENA Countries (1973–2008)	DOLS, FMOLS, Panel cointegration	E, Y, CO2	E ≠Y, Y→CO2, CO2→ E
[159]	Kahsai (2012)	SSA (1980–2007)	Panel cointegration,	E, Y	E2Y
[160]	Kwakwa (2012)	Ghana (1971–2007)	ADF, Granger, VECM	E, Y, ELEC, NRE, Agr, Man	Ghana, Y→ELC, Y→NRE, Agr ≠Y
[161]	Okafor (2012)	Nigeria, South Africa	Hsiao- Granger	E, Y, Coal, Hydro, Oil, Gas	Nigeria, E→Y, South Africa Y→E
[162]	Sebri & Abid (2012)	Tunisia (1980–2007)	VECM	E, Y, Agricultural, Residential, Transport, Industrial, Tertiary Energy	Tunisia, Y→E
[163]	Souhila & Kourbali (2012)	Algeria (1965–2008)	Threshold cointegration, Granger	E, Y	Algeria, Y→E
[164]	Adhikari & Chang (2013)	LDCS (1990–2009)	DOLS, Fisher- ADF, Fisher Peron	E, Y	E →Y
[165]	Amar(2013)	23 Africa (1980–2009),	DOLS, FMOLS, Fisher-ADF, IPS, Granger	E, Y, K,L	Y→E
[166]	Amusa & Leshoro (2013)	Botswana (1980–2008)	ARDL Bounds cointegration	E, ELC, Y	Botswana, E→Y
[167]	Damette & Seghir (2013)	12 OPEC (1990–2008)	PPC	E, Y	OPEC, Y→E
[168]	Fatai (2013)	18 SSA (1980–2011)	Panel cointegration causality, LLC, ADF, PP	E, Y	E →Y (East & South Africa), E≠Y (Central & West Africa)
[169]	Fondja Wandji (2013)	Cameroon (1971–2009)	ECM, DF, ADF	E, ELC, Y, Biofuels, Oil,	Cameroon, E →Y, Y≠ELC, Y≠Biofuel
[170]	Olusanya (2013)	Nigeria (1970–2010)	Granger	E, Y, FDI	Nigeria, E→Y
[171]	Omri (2013)	14 MENA (1990–2011)	GMM	E, Y, CO2	E→Y, E→CO2
[172]	Ogundipe & Oyomide (2013)	Nigeria (1980–2010)	VECM, Pairwise Granger, Johansen	ELC, Y, K, L	Nigeria, ELC 2Y
[173]	Ogundipe (2013)	Nigeria (1980–2010)	VECM, Pairwise Granger, Johansen	ELC, Y, K, L	Nigeria, ELC 2Y
[174]	Akomolafe & Danladi (2014)	Nigeria (1990–2011)	ADF, PP, Johansen	E, ELC, Y	Nigeria, ELC→Y, K→Y
[175]	Adom & Kwakwa (2014)	Ghana (1980–2010)	ECM	E, Y, K, L, Urbanisation	Ghana, E→Y, Urb→E
[176]	Kwakwa & Aboagye (2014)	Ghana	ECM	E, Y, K, L, TO	Ghana, E→Y

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Table 2 (*continued*)

A/No	Author	Country	Method	Variables	Results
[174]	Omri (2014)	MENA (1970–2012)	DGE	E, FDI,Y, ELC	E→Y
[177]	Oyaromade et al. (2014)	Nigeria (1990–2010)	ADF, PP	E, Oil, Real Y	Nigeria, E ≠Y
[178]	Tang & Abosedra (2014)	24 MENA	GMM, POLS, Arellano-Bond	E Per capita, Real Y per capita, Tourism, Political Stability	E →Y, T→ Y
[179]	Antai, Udo, & Ikpe (2015)	Nigeria (1970–2009)	Multiple regression, Granger	E, ELC, Y	Nigeria, ELC2Y
[180]	Dlamini, Balcilar, Gupta, & Roula Inglesi-Lotz, (2016).	South Africa (1971–2008)	VAR, Granger	E, Y	South Africa, E→ Y
[181]	Kais & Mbarek (2015)	(Algeria, Egypt, Tunisia) (1980–2012)	VECM	E, Y, CO2	E→CO2, E→Y
[182]	Kananura (2015)	Uganda (1960–2014)	ARDL, ECM Pairwise Granger	ELC,Y	Uganda, ELC→Y
[183]	Solarin & Ozturk (2015 a)	12 OPEC	PPC	E, Y, Natural Gas	Y→E (Bahrain)) E≠Y (Oman, Saudi Arabia, UAE)
[184]	Achour & Belloumi (2016).	Tunisia (1971–2012)	Johansen	Transport Infrastructure (TI), Transport CO2, Transport Capital formation, (TK) Transport energy consumption TREC), Transport Value added (TVA)	Tunisia TVA →TI, TCO2P→TI, TK→TI
[185]	Adams et al. (2016)	16 SSA (1971–2013)	GMM, PVAR, VDC, IRF	E, Y, EP, TO	EP→Y, E2Y, TO→Y
[186]	Alege, Adediran, & Ogundipe (2016).	Nigeria (1970–2013)	Johansen	E, CLEC, CO2, Y, ELC, Fossils	Nigeria, E→Y, Oil ≠Y
[187]	Bildirici & Özaksoy (2016)	SSA (1980–2013)	ARDL	E, BEC, Y	BEC2Y (Benin, Mauritania, Nigeria and South Africa) Y→BEC (Seychelles), BEC→Y (Angola, Guinea-Bissau and Niger)
	Destek (2016 b)	South Africa (1971–2009)	AR, Bootstrap rolling window	E, Y	South Africa, E→Y
[188]	Destek (2016 c)	NICs (1971–2011),			
[189]	Dlamini, Balcilar, Gupta, & Roula Inglesi-Lotz, (2016).	South Africa (1971–2008)	VAR, Granger	E, Y	S > Africa, E ≠Y
[190]	Dogan (2016)	South Africa, Malaysia, India, Brazil	Asymmetric causality	E, Y	E→Y (+) (S. Africa, Mexico, E→Y (−) (India), E ≠Y (Brazil, Malaysia)
[191]	Esso Keho (2016)	12 SSA (1971–2010)	ECM, Granger, VAR	E, Y, CO2, Y	Y2CO2, (Congo, Gabon) CO2→Y (Gabon, Nigereria, Togo), E→CO2 (Benin, Ivory coast, Senegal, South Africa), Y→CO2
[5]	Mawejje & Mawejje (2016)	Uganda (1971–2011)	VECM, Gramger	ELC, AGR. IND, Com Y	E ≠AGR Y, E→Ind Y
[192]	Sekantsi & Thamae (2016)	Lesotho (1972–201)	ARDL, Pesaran-Shin	E, Y	Lesotho, E→Y (+)
[31]	Sekantsi & Motlokoa (2016)	Uganda (1982–2013)	VAR	E, Y	Uganda, ELC→Y
[4]	Sekantsi & Okot (2016)	Uganda (1981–2013)	ARDL	E, Y	Uganda, ELC→Y
[193]	Mutumba et al. (2024)	Uganda (1981–2018)	VECM, SVAR, Granger	E, REC, DINV, FDI	Uganda, REC→Y
[194]	Otim et al. (2022)	Uganda (1986–2018)	VECM, Granger	E, Y, CO2	Uganda E≠CO2, Y→ CO2
[195]	Solarin et al. (2016)	Angola (1990–2014)	Granger	E, Y, Trade, Urb	Angola, Y→E
[196]	Ameyaw, Oppong, Abruquah, and Ashalley (2017)	Ghana (1970–2014)	VECM, Granger Cobb-Douglas	E, Y, ELC	Ghana, Y→ ELC
[197]	Aneja et al. (2017)	BRICS (1990–2012)	PPC, PECM	E, RE, NRE, Y, CO2	Y→ E
[198]	Anwar et al. (2017)	29 OICs (1990–2014)	Panel cointegration & Causality	E, NRE, RE, Y, BOP	RE→Y, RE→BOP, E→Y
[199]	Awodumi & Adewuyi (2017)	AF- OPEC Algeria, Angola, Gabon, Nigeria	3SLS	E, Y	E≠Y
[200]	Awodumi & Adewuyi (2017)	West Africa	PDT	BEC, Y	BEC→Y
[201]	Awodumi & Adewuyi (2017)	AF- OPEC Algeria, Angola, Gabon, Nigeria	PRT	RE, NRE,Y	E ≠Y
[202]	Bah & Azam (2017)	South Africa (1971–2012	ARDL,TY, Augmented, ADF Granger	ELC, Y, FD, CO2	South Africa, ELC→Y
[203]	Bildirici & Ozaksoy (2017)	Africa (1980–2012)	NARDL, ARDL, Granger VDC	E, Real Y per capita, BEC	Africa, Y→BEC(Botswana, Cameroon, Uganda, Zambia), BEC→Y (Burkina Faso, CAR, Ivory coast, Djibouti, Gabon, Lesotho, Zimbabwe), BEC2Y (Kenya, Lesotho, Mali, Togo)

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A/No	Author	Country	Method	Variables	Results
[204]	Charfeddine & Mrabet (2017)	15 MENA	Markov Swicthing	E, Y, EF, Urb, PII, Fertility rate, Life Exp	E2Y
[205]	Chang et al. (2017)	BRICS (1985–2015)	Panel cointegration	E, Real Coal consumption, Y	Coal≠Y, (All Short run), Coal →Y China, India), Y→ Coal (South Africa)
	Hammani (2017)	17 MENA (1980–2012)	GMM	E, Y, FDI	Y2FDI, E→Y
[206]	Chingoiro & Mbulawa (2017)	Botswana (1980–2014)	VECM	E, ELEC, Y, K, L, Inflation	Botswana, ELC→ Y
[207]	Appiah (2018)	Ghana (1960–2015)	TY, Granger	E, Y, CO2	Ghana, E2CO2, E→Y
[208]	Bouznit et al. (2018)	Algeria (1970–2013)	ARDL	E per capita,Y Per capita, Residential electricity per capita	Algeria, Y→E
[209]	Elfaki et al. (2018)	Sudan (1984–2014)	ARDL	E, Real Y, K, Trade Openness, Urb	Sudan, E→Y
[210]	Ibrahiem (2018)	Egypt (1971–2013)	VECM, Johansen	E, Y	Egypt
[211]	Sunde (2018)	South Africa (1970–2013)	ARDL, ECM	E,Y	South Africa, E2Y
[212]	Twerefou et al. (2018)	West Africa	DOLS, FMOLS, PECM, LLC, IPS	E, Y	E2Y
[213]	Yildirim & Yildirim (2018)	BRICS-T (1990–2014)	FMOLS, Pedroni, Westerlund & Edgerton	E,Y	Y→E
[214]	Nkengfack & Fotio (2019)	Algeria (1971–2015), Egypt, (1971–2015), South Africa, (1971–2015).		E,Y, CO2	E →Y (+), E→ CO2
[215]	Nathaniel & Bekun (2019)	Nigeria (1971–2014)	FMOLS, DOLS, Bound, Bayer & Hunch	ELC, Y	Nigeria, E →Y
[216]	Shiba et al. (2019)	South Africa (1980–2014)	ARDL, ADF, PP	E, ELEC, Y, Inflation	South Africa, E→Y, ELC≠ Y
[217]	Zallé (2019)	Africa countries. (2000–2015)	ARDL	E,Y	E→Y
[218]	Awodumi Adewuyi (2020)	&AF- OPEC Algeria, Angola, Egypt Gabon, Nigeria	NARDL	E, Y, CO2, K, L, Petrol,	Gas E→Y (+) (Algeria), E→Y (−) (Angola, Egypt, Nigeria)
	Awodumi & Adewuyi (2020)	Africa (1980–2015) (Algeria, Angola, Egypt, Gabon, Nigeria).	ARDL	E, Y, CO2, K, L, Petrol,	Gas E→Y (+) (Algeria), E→Y (−) (Angola, Egypt Nigeria)
[219]	Chimbo (2020)	Selected African Countries, (2001–2015),	GMM, POLS, FE, RE	E, ICT, Y, K, Human Dev't	ICT→Y, Y→E, ICT→HD (+), ICT→E (−)
[220]	Ferdaus et al. (2020)	Bangladesh, (1990–2015), Egypt, (1990–2015), Indonesia, (1990–2015), Iran, (1990–2015), Mexico, (1990–2015) Nigeria, (1990–2015), Pakistan, (1990–2015) Philippines, (1990–2015) South Korea, (1990–2015) Turkey, (1990–2015), Vietnam (1990–2015).	ARDL, VECM	E, Y, EP, K, L	E→EP (−), E→Y,EP→Y
[221]	Lawal et al. (2020)	Africa (1971–2017)	GMM, Dynamic Panel Threshold	ELC, Y, Macroeconomic proxy (Z)	ELEC→Y
[222]	Rahman & Velayutham (2020)	South Africa (1990–2014)	Dumitrescue & Hurlin (2012), Kao, Pedroni	E, NRE, RE,Y	South Africa, Y→RE
[223]	Sapnken et al. (2020)	Cameroon (1994–2014)	ARDL, VAR, Granger, TY	E, LPG, Kerosene, Y, EP, Urb	Cameroon, LPG2Y, Y→Ker, Urb→Ker, Price→Ker
[224]	Sunde (2020)	SADC (1971–2014)	Granger	E, Y	Y→E (Angola, DR Congo, Mauritius, Namibia), E2Y (Botswana, Mauritius), E≠Y (Mozambique, South Africa, Zambia, Zimbabwe).
[225]	Topcu et al. (2020)	124 Countries (1980–2014)	PVAR	E, Y, Natural Resources (NR), K, Urb.	E→Y, NR→Y, Urb→Y
[226]	Tsaurai & Ngcoba (2020)	BRICS (1994–2015), (Brazil, China, Russia, South Africa)	FMOLS, POLS, PP, LLC, Johansen- Fisher	E, RE, Y, FDI, Savings, Infrastructure, TO, HCD (Education),	BRICS, RE→Y (+), HCD→Y
[227]	Uzokwe & Onyipe 2020)	Nigeria (1984–2015)	ARDL, VAR	E, NRE, RE, Y, CO2	Nigeria, RE→Y
[228]	Al- Tal et al. (2021)	MENA (2003–2018)	POLS, FE	E,Y, Political Stability, Government effectiveness, Quality of Governance	MENA, G →E, E →Y (−)
[229]	Musa & Bako (2021)	Nigeria (1996–2014)	VECM, JOJU	E,Y, International Trade, CO2	Int Trade→Y, CO2→Y, Y→E, CO2 →Int Trade
[230]	Nathaniel & Adeleyi (2021)	44 African (1992–2016)	PSSC, PCSE System GMM	E,Y, CO2, K, L, FD, Urb	E →CO2 (−), Urb→CO2 (+), FD→Y, K→CO2 (+)
[15]	Odhiambo (2020)	Botswana, (1980–2016)	ARDL Bounds testing, Pesara-Shin, Pesaran-Shin- Smith	E,ELEC, Y, Gasoline, Gas, Oil and Liquefied, TO, Inflation	Botswana, E→Y
[231]	Okoye et al. (2021)	Nigeria (1981–2017)	ARDL	E, Y, ELC, Fixed Capital	Nigeria, E→Y
[232]	Syzdykova et al. (2021)	LDCs (1990–2019)	GMM, Arelleno- Bond (1991), Arellano-Bover (1995), Arellano- Wu (1999)	E, RE, Y, Fossil energy consumption (FEC), Energy tax, energy saving	RE→ Y
[3]	Mutumba et al. (2022a)	Uganda (2008–2018)	VECM, Granger	ELC, K, L, Y	Uganda, ELC2Y
[41]	Mutumba et al. (2022b)	Uganda (1990–2015)	ARDL, MWald Granger	RE, NRE, K, L, RELCT, TO, Y	Uganda, RE→Y (−), NRE→Y (+)

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A/No	Author	Country	Method	Variables	Results
[233]	Mutumba et al. (2022)	Uganda (1988–2018)	VECM, Granger	RE, K, L, TO, CO2, Y	Uganda RE→Y (−)
[234]	Mutumba et al. (2024)	Uganda (1982–2018)	VECM, SVAR, Granger	E, RE, DINV, FDI, Y	Uganda RE→Y (+)

Source: Adapted from [2].

H0.

$\gamma = 0$ for $j = 1, \ldots, n$

$$H_1 : \alpha \neq 0 \text{ for at least one } j \quad (4)$$

where μ is a constant and u_t is a white noise process.

The pairwise Granger gives one type of causality that shows the predictive power of one variable say economic growth, given past values of the other, such as electricity consumption. So it may not be relied upon solely to establish causality between two variables. Additionally, to increase robustness of causality results of the panel [230], the Dumitrescu and Hurlin (2012) test was used to confirm the direction of causality between the variables in this study.

The order of integration of the variables of the study was ascertained. Subsequently, a long-run relationship is established using the Kao Pedroni test statistic. At least one cointegrating relationship exists within the series, justifying the use of panel dynamic ordinary least squares (DOLS). DOLS is superior to the ordinary least squares (OLS) method, which can provide accurate estimates in the presence of endogeneity and serial correlation problems. Furthermore, DOLS is robust in overcoming the heteroskedasticity and cross-sectional dependence problems. This study therefore preferred to use the DOLS to handle the issue of endogeneity.

According to Ref. [238], variables suspected of being endogenous are regressed on the first difference to minimize endogeneity. The endogeneity problem between electricity consumption and per capita GDP cannot be overlooked in this study. Thereafter, the OLS method is induced on the residuals of the regression from first principles.

The panel fully modified ordinary least squares (FMOS) model was also adopted. The strength of using FMOLS lies in mitigating the cross-sectional dependence problem [239]. Because of cross-sectional dependence (CD), Phillips and Hansen fully modified ordinary least squares model was used. The advantage of the FMOLS estimator is that it is unbiased and asymptotically efficient. It also considers non-parametric estimation consistency. Cross-sectional dependence was a deep-seated problem in our data arising from two main issues: spill overs and unobservable factors between regions. These factors include technology and technological transfers, Capital inflows and international trade amongst members implying that CD can no longer measure up to solve the key issues of this study.

The panel nonlinear autoregressive distributed lag (NARDL) was carried out, as shown in Table 12. The justification for the choice of NARDL was mainly the non-asymmetric data for selected variables (real electricity trade and trade openness). These exhibited nonlinearity over the series, and the NARDL model was appropriate for overcoming this econometric issue.

Modeling must be performed taking care of this cross-sectional dependence. This withstanding, a Hausman CD test was performed to determine whether a fixed or random effects model was more appropriate. The fixed model is operated when time-invariant variables exist for time-variant effects and the specific effects are random variables that are correlated with the explanatory variable [81].

The panel DOLS and FMOLS are superior techniques in the analysis in that they address endogeneity by adding leads and lags, and overcome the white heteroskedasticity standard errors. They also manage small sample biases by considering the first-difference regressors.

The diagnostic tests are post-estimation tests, particularly to establish stationarity and unit root, serial correlation, functional form, cointegration, heteroskedasticity, and normality. First to establish stationarity in the variables of study, the study implored the Panel Augmented Dickey Fuller (PADF) [240] Levin Lin and Chu (2003) (LLC), Im Pesaran and Shin W- statistic, ADF Fisher and PP-fisher chi square test. According to Dickey and Fuller (1979), the null hypothesis states that all variables have unit roots. The electricity consumption (E) was stationary at the first difference. The appropriate lags must be confirmed based on the rationale that past values impact those of today. There are several ways to identify the appropriate lags. The AIC was used to identify the lag length, given a sample of 31 observations. The appropriate lag length was 2.

The cointegration test confirms a long-run relationship between the study variables. The Kao Pedroni test statistics suggest the existence of at least one cointegrating relationship between per capita GDP and electricity consumption [241]. The presence of cross-section dependence makes the FMOLS a suitable econometric model.

The choice of econometric models is due to the existence of both cointegration and cross-sectional dependence problems. Because the error structure is nonstationary in levels, the problem is estimated in a first-difference formulation [242]. The Augmented Dickey Fuller- Fisher test was used to determine whether the series was stationary, and the Phillips–Peron test was applied to confirm the unit root process.

If the set-up has a correct functional form, and the independent variables are well identified, yet commit functional form not well expressed. This introduces misspecification bias in the model. In such a stance, the model may not accurately explain the relationship between the dependent and observed independent variables. In this study, Ramsey RESET (regression specification error test (RESET) is used to

Table 3
Variable description and expected signs.

Variables	Symbol	Measure	Expected Sign	Data source
Gross Domestic Product Per capita	$PGDP_t$	Per capita GDP constant 2010 US$	+	World Bank: World development indicators (WDI)
Gross capital formation	GCF_t	GDP constant 2010 US$	+	World Bank: World development indicators (WDI)
Total labour force	LBR_t	Total labour force	+	World Bank: World development indicators (WDI).
Trade Openness	OPN_t	$(\text{Export} + \text{Import})/_{GDP}$	+	World Bank: World development indicators (WDI).
Real Electricity trade	ELT_t	(Electricity Exports + Imports)	+	World Bank: World development indicators (WDI)
Electricity net consumption	ELC_t	kWh	+	International Energy Agency (IEA)

Source: Source: Author's analysis based on data from World Bank, International Energy Agency

ensure the correct specification.

To test and confirm that the error term (μ_t) is not homoscedastic using the Breush–Pagan–Godfrey test, which provides stable estimates and minimizes residual errors. The μ_t term is independently and identically distributed (i.i.d). Using the correlogram, the μ_t term of this setup is obtained. The step of transforming these variables is important in stabilizing the means, which are inherently non-stationary in this study.

The test for normality used in this study was the Jacque-Bera normality test. The condition that the model has a linear relationship among variables is handled by the Jacque–Bera test. The condition for normality is that the probability of the Jacque–Bera statistic must be insignificant at the 5 percent significance level. Using maximum likelihood autoregressive conditional heteroskedasticity (ML-ARCH), the residuals were found to be normally distributed.

The Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Nonlinear Autoregressive Distributed Lag (NARDL) models are advanced econometric techniques used to analyse the relationship between dependent and independent variables, particularly in the context of time series data. These models are especially relevant in studies examining the dynamics between electricity consumption and economic growth, incorporating variables such as Gross Capital Formation (GCF), total Labour Force (TLF), Trade Openness (OPN), Real Electricity Trade (ELT), and Electricity Net Consumption (ELC), with GDP per capita as the dependent variable. FMOLS is a technique designed to correct for serial correlation and endogeneity in cointegrated systems, providing unbiased long-run estimates even in the presence of endogeneity and autocorrelation [243] (Kassi et al., 2023). The FMOLS estimator is given by equation (5):

$$\widehat{\beta}_{FMOLS} = \left(\sum_{t=1}^{T} \widetilde{X}_t' \widetilde{X}_t \right)^{-1} \sum_{t=1}^{T} \widetilde{X}_t' \widetilde{Y}_t \tag{5}$$

Where $\widetilde{X}_t$ and $\widetilde{Y}_t$ are modified series of the independent and dependent variables, respectively. DOLS, on the other hand, extends the OLS framework to include leads and lags of the first differences of the independent variables to address the issue of endogeneity and serial correlation in cointegrated systems [244,244]. The DOLS model can be represented in equation (6) as:

$$\Delta Y_t = \alpha + \sum_{i=-k}^{k} \beta_i \Delta X_{t+i} + \gamma X_{t-1} + \epsilon_t \tag{6}$$

where Δ denotes the first difference, k is the number of leads and lags, and ϵ_t is the error term. The equation for FMOLS and DOLS can be represented in equation (7) as:

$$GDP_{pc} = \alpha + \beta_1 GCF + \beta_2 GLF + \beta_3 OPN + \beta_4 ELT + \beta_5 ELC + \epsilon \tag{7}$$

where α is the intercept, β_1 to β_5 are the long-term coefficients of the independent variables, and ϵ is the error term

NARDL, a flexible approach to modeling asymmetric adjustments to changes in the independent variables, allows for different short- and long-run dynamics depending on whether the changes in the independent variables are positive or negative [245]. The NARDL model can be specified in equation (8):

$$\Delta Y_t = \varphi_0 + \sum_{j=1}^{p} \varphi_j \Delta Y_{t-j} + \sum_{i=0}^{q} \theta_i^{+} \Delta X_{t-i}^{+} + \sum_{i=0}^{q} \theta_i^{-} \Delta X_{t-i}^{-} + \epsilon_t \tag{8}$$

where X^{+} and X^{-} represent positive and negative changes in the independent variables, respectively. The NARDL model is specified as in equation (9):

$$\Delta GDPpc_t = \varphi_0 + \sum_{j=1}^{p} \varphi_j \Delta GDPpc_{t-j} + \sum_{i=0}^{q} \left\{ \varphi_i^{+} \Delta X_{it}^{+} + \varphi_i^{-} \Delta X_{it}^{-} \right\} + \epsilon_t \tag{9}$$

Where Δ represents the change in the variables, X_{it}^{+} and X_{it}^{-} denote the positive and negative changes in the independent variables, respectively, and φ_0, φ_j and φ_i are the coefficients to be estimated.

Investigations into the relationship between Electricity Consumption and Economic Growth utilizing various econometric models such as Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Non-linear Autoregressive Distributed Lag (NARDL) models have provided valuable insights. FMOLS and DOLS have proven effective in estimating long-run relationships and correcting for econometric issues, whereas NARDL has allowed for the examination of the asymmetric effects of independent variables on economic growth. By combining these methodologies, a comprehensive analysis of how electricity consumption influences economic growth in different ways was achieved, enhancing our understanding of this complex relationship [246,245,247–250]..

5. Findings and discussion

The descriptive statistics are shown in Table 4. Descriptive statistics of the main variables included the mean, median, and standard deviation for each variable (see Table 5).

From Tables 4 and it is observed that the means are positive for all variables, except trade openness. The probability of the Jacque-Berra statistic shows that the log-transformed values of all the variables are normally distributed.

The kurtosis for indicating concentration around the mean shows that five out of six variables had a kurtosis below 3. Data limitations existed in this study, and hence the relevance of carrying out pre- and post-estimation tests.

To test for presence of unit roots in the panel data series, we employed the Augmented Dickey Fuller (ADF) - Fisher and Levin, Lin and Lu (LLC 2003), Im Pesaran Shin and Phillip - Peron (PP)- Fisher chi square results show that all variables are not stationary in levels but stationary at first difference as shown in Table 6. Stationarity is an indicator of the stability of the variables in the model, and the unit root process can be measured [251]. To ensure stability we used ADF- Fisher test and others were confirmatory in establishing a unit root. This is a precondition for carrying out a cointegration test to establish a long run relationship among the variables [1153].

The cointegration test for establishing a long-run relationship among our panel series was carried out using the Kao (Engle Granger) [252], Pedroni residual, and Panel Johansen Fisher cointegration tests, shown in Tables 6, 7,8, and 13, respectively.

The Pedroni and Kao (1999) cointegration test statistic suggests the existence of at least one co-integrating relationship between GDP (LGDP) and electricity consumption (LELC), which is a single-tailed statistic that reveals a long-term equilibrium and uses a *t*-test statistic pooled within an individual country. Therefore, we reject the null hypothesis at the 5 % level of significance; thus, we establish the cointegration using the Kao test results, which show that a positive and significant relationship exists between electricity consumption and economic growth, as shown in Table 6.

The random effects model was more appropriate than the fixed effects model in analysing a dynamic equilibrium between variables of interest in this study, as shown by the Pesaran scaled lag range multiplier test in Table 8 was used.

Cross-section dependence was carried out using the Hausman test, and the results indicate the presence of cross-sectional dependence shown in Table 9, whose results are significant at the 5 percent level of significance. Therefore, this was a good justification for using the FMOLS and random-effects model in this study.

The results of the DOLS in Table 10 indicate significant results for electricity consumption and economic growth. A 1 percent increase in electricity consumption causes a 0.007 percent reduction in GDP. A 1 percent increase in gross capital formation causes a 0.44 percent increase in GDP, and a 1 percent increase in total labour force causes a

Table 4
Summary statistics of the variables before Log transformation.

	PGDP	ELC	ELT	GCF	LBR	OPN	GDP_L1
Mean	5.999	6.880	4.418	7.260	2.062	−0.938	8.915
Median	5.936	6.930	4.554	7.3571	2.216	−0.964	8.909
Maximum	7.635	9.114	5.826	10.285	3.379	−0.252	11.519
Minimum	4.718	4.762	2.708	3.187	0.529	−1.619	6.625
Std. Dev.	0.721	1.406	0.690	1.698	0.798	0.306	1.321
Skewness	0.294	−0.090	−0.457	−0.209	−0.135	0.021	0.0810
Kurtosis	2.065	1.591	2.804	2.235	1.606	2.293	2.009
Jarque-Bera	8.131	13.454	5.828	5.066	13.432	3.340	6.716
Probability	0.017	0.001	0.054	0.079	0.001	0.188	0.035
Sum	959.811	1100.776	706.897	1161.630	329.874	−150.047	1426.322
Sum Sq. Dev.	82.605	314.518	75.684	458.583	101.259	14.919	277.118
Observations	160	160	160	160	160	160	160

Source: Author's analysis based on data from World Bank, International Energy Agency

Table 5
Results from panel unit root tests.

Variables in Levels	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square
LPGDP	0.440	2.459	1.566	1.977
LELC	1.816	3.980	0.700	0.557
LELT	−2.210	−1.415	14.152	13.728
LGCF	0.364	2.510	1.487	1.170
LLBR	−0.704	4.251	9.114	4.856
LOPN	−0.306	−1.678	20.044	14.402
LGDP_L1	1.065	3.480	0.674	0.638
Variables in First Difference	**Levin, Lin & Chu t***	**Im, Pesaran and Shin W-stat**	**ADF - Fisher Chi-square**	**PP - Fisher Chi-square**
D (LPGDP)	−9.510[a]	−8.926[a]	80.619[a]	80.749[a]
D (LELC)	−9.890[a]	−12.786[a]	119.895[a]	125.056[a]
D (LELT)	−13.600[a]	−12.690[a]	120.942[a]	128.549[a]
D (LGCF)	−10.586[a]	−9.318[a]	85.832[a]	86.180[a]
D (LLBR)	−4.447[a]	−5.324[a]	50.102[a]	53.658[a]
D (LOPN)	−8.022[a]	−8.386[b]	77.375[a]	118.800[a]
D (LGDP_L1)	−6.411[a]	−5.759[a]	50.511[a]	68.197[a]

[a] Significant at 1 % level of significance.
[b] Significant at 5 % level of significance.
Source: Author's analysis based on data from World Bank, International Energy Agency

Table 6
Results from Kao (Engle-Granger based) residual cointegration test.

	t-Statistic	Prob.
ADF	−3.965	0.0000
Residual variance	0.007	
HAC variance	0.003	
Augmented Dickey-Fuller Test Equation: Dependent Variable: D (RESID)		

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RESID (-1)	−0.417	0.082	−5.070	0.000
D (RESID (-1))	−0.241	0.078	−3.061	0.003
R-squared	0.324	Mean dependent var		0.002
Adjusted R-squared	0.320	S.D. dependent var		0.106
S.E. of regression	0.088	Akaike info criterion		−2.016
Sum squared resid	1.139	Schwarz criterion		−1.975
Log likelihood	153.163	Durbin-Watson stat		2.063

Table 7
Pedroni Residual cointegration.

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	0.585	0.279	−0.164	0.565
Panel rho-Statistic	0.245	0.597	1.098	0.864
Panel PP-Statistic	−4.064	0.000	−2.626	0.004
Panel ADF-Statistic	−0.275	0.392	0.186	0.574
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	0.845	0.801		
Group PP-Statistic	−6.105	0.000		
Group ADF-Statistic	−1.545	0.061		
Cross section specific results				
Phillips-Peron results (non-parametric)				

Cross ID	AR (1)	Variance	HAC	Bandwidth	Obs
Uganda	0.024	0.004	0.004	3.00	31
Tanzania	0.654	0.004	0.004	3.00	31
Kenya	0.302	0.002	0.000	14.00	31
Burundi	−0.237	0.004	0.003	3.00	31
Rwanda	−0.241	0.002	0.001	13.00	31

Source: Author's analysis based on data from World Bank, International Energy Agency

Table 8
Results from Hausman cross-sectional dependence tests - Random effects model.

Test	Statistic	Prob.
Breusch-Pagan LM	28.98653[a]	0.0013
Pesaran scaled LM	4.245518[a]	0.0000
Bias-corrected scaled LM	4.164872[a]	0.0000
Pesaran CD	3.090309[a]	0.0020

[a] Significant at 99 % confidence level.

0.43 percent decrease in GDP. Both capital and total labour force are significant at the 1 percent level. A 1 percent increase in the real electricity trade causes a 0.04 percent decrease in GDP. A 1 percent increase in trade openness causes a 0.13 percent decrease in GDP.

Table 11 presents the results of the FMOLS estimation. FMOLS indicates a significant relationship between electricity consumption and economic growth. A 1 percent increase in electricity consumption causes a 0.009 percent decrease in GDP, which is significant at 1 percent level of significance. While a 1 percent increase in gross capital formation causes a0.42 percent increase in GDP and a 1 percent increase in total labour force causes a 0.47 percent decrease in GDP. A 1 percent increase in real electricity trade causes a 0.04 percent decrease in GDP and a 1 percent increase in trade openness causes a 0.12 percent decrease in GDP.

This is in agreement with earlier studies that electricity may make a small contribution in terms of the cost-share theorem (140, 142]. In fact, using per capita GDP is more robust, because it is sensitive to the distribution effect. This finding indicates an inverse relationship with economic growth.

As shown in Table 12, the results of the panel nonlinear autoregressive distributed lag indicate a significant relationship between gross capital formation, total labour force, trade openness, and per capita

Table 9
Correlated Random effects Hausman test for the appropriate model.

Test Summary		Chi-Sq. Statistic		Prob.
Cross-section random		11.11		0.085
Cross-section random effects test comparisons				
Variable	Fixed	Random	Var (Diff.)	Prob.
LELC	0.097	0.095	0.000	0.882
LELT	0.257	0.263	0.000	0.635
LGCF	0.127	0.124	0.000	0.301
LLBR	0.239	0.215	0.000	0.157
LOPN	−0.058	−0.054	0.000	0.533
LGDP_L1	0.616	0.633	0.000	0.048

Source: Source: Author's analysis based on data from World Bank, International Energy Agency

Table 10
Results from Panel Dynamic Least Squares (DOLS) estimation.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LELC	−0.007	0.075	−0.088	0.930
LELT	−0.042	0.024	−1.747	0.083
LGCF	0.437	0.041	10.727	0.000
LLBR	−0.427	0.179	−2.390	0.018
LOPN	−0.134	0.040	−3.310	0.001
LGDP_L1	0.306	0.053	5.805	0.000
R-squared	0.656	Mean dependent var		5.999
Adjusted R-squared	0.633	S.D. dependent var		0.721
S.E. of regression	0.437	Long-run variance		0.006

Source: Author's analysis based on data from World Bank, International Energy Agency

Table 11
Results from Panel Fully Modified Least Squares (FMOLS) estimation.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LELC	−0.010	0.043	−0.231	0.818
LELT	−0.041	0.015	−2.845	0.005
LGCF	0.424	0.024	17.683	0.000
LLBR	−0.47	0.106	−4.426	0.000
LOPN	−0.124	0.027	−4.638	0.000
LGDP_L1	0.331	0.031	10.807	0.000
R-squared	0.552	Mean dependent var		6.014
Adjusted R-squared	0.521	S.D. dependent var		0.726
S.E. of regression	0.502	Long-run variance		0.002

Source: Author's analysis based on data from World Bank, International Energy Agency

GDP. This finding is consistent with the findings from the DOLS and FMOLS with regard to gross capital formation and total labour force.

While analysing short run causality dynamics in this study, we employed the Wald test for short run causality, the results are significant as shown in Table 14 in appendix. A short-run causality exists between all variables and GDP, except for electricity trade. The single direction of causality between electricity consumption and economic growth in the short run, as shown by the Wald test, is not evident in the long run, which is in agreement with earlier studies [17,18].

The long-run causality dynamics in this study are analysed by the panel pairwise Granger causality shown in Table 13 and the Dumistreschu–Hurlin (2012) panel causality test. Both Table 13 and 14 are detailing the causal relationship panel of the entire and from this, it can be deduced from the pairwise Granger causality from Table 13 that.

(i) A single direction causal relationship from net electricity consumption to economic growth at a 5 percent level of significance. This implies that increasing investment in Electricity will lead to GDP growth in E.A-5.
(ii) Gross capital formation Granger causes Economic growth at a 5 percent level of significance.

Table 12
Panel Nonlinear Auto Regressive Distributed Lag (NARDL) model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
Long Run Equation				
LELC	−1.588	1.200	−1.323	0.190
LELT	−0.833	0.607	−1.371	0.174
LGDP_L1	2.363	1.263	1.871	0.065
Short Run Equation				
COINTEQ01	0.145	0.077	1.886	0.063
D (LPGDP (-1))	−10.965	7.851	−1.397	0.167
D (LPGDP (-2))	10.423	8.173	1.276	0.206
D (LPGDP (-3))	−7.808	8.134	−0.960	0.340
D (LELC)	−0.0737	0.207	−0.356	0.723
D (LELC (-1))	−0.052	0.080	−0.652	0.517
D (LELC (-2))	0.194	0.205	0.948	0.346
D (LELC (-3))	0.038	0.146	0.260	0.795
D (LELT)	−0.140	0.077	−1.805	0.075
D (LELT (-1))	−0.053	0.036	−1.474	0.145
D (LELT (-2))	−0.007	0.086	−0.076	0.939
D (LELT (-3))	−0.075	0.052	−1.440	0.151
D (LGDP_L1)	11.245	7.857	1.431	0.157
D (LGDP_L1 (-1))	−10.020	8.312	−1.206	0.232
D (LGDP_L1 (-2))	7.944	8.022	0.990	0.325
D (LGDP_L1 (-3))	0.071	0.106	0.669	0.505
C	−0.146	0.224	−0.650	0.518
Mean dependent var	0.0525	S.D. dependent var		0.136
S.E. of regression	0.0901	Akaike info criterion		−1.505
Sum squared resid	0.585	Schwarz criterion		0.187
Log likelihood	208.398	Hannan-Quinn criter.		−0.818

(iii) Total labour force Granger causes economic growth at a 5 percent level of significance
(iv) Gross capital formation Granger causes net electricity consumption
(v) Real electricity trade Granger causes net electricity consumption at a 5 percent level of significance
(vi) Trade openness has a bidirectional causality with economic growth
(vii) Gross labour has a unidirectional causality with net electricity consumption at a10 percent level of significance
(viii) Total labour force has a unidirectional causality with real electricity trade at 10 percent level of significance

While the panel Dumistrescu- Hurlin (2012) test in Table 14 it can be deduced that.

(i) A unidirectional causal relationship running from electricity consumption to economic growth at the 1 percent level of significance. This gives a definitive causal relationship, meaning investing in electricty consumption will ultimately lead to economic growth in the region of study.
(ii) A unidirectional causal relationship running from electricity trade to economic growth at a 1 percent level of significance.
(iii) A unidirectional causality from Gross capital formation to economic growth
(iv) A unidirectional causality from trade openness to economic growth
(v) A unidirectional causality from net electricity consumption to economic trade openness
(vi) A bidirectional causal relationship between total labour force and economic growth, gross capital formation and net electricity consumption.

5.1. Discussion of empirical results

The empirical results from the multivariate framework support growth hypothesis this implies that electricity makes a substantial contribution to economic growth. This is in agreement with the results of

Table 13
Pairwise Granger Causality (Stacked test – common coefficients) Analysis.

Null Hypothesis:	Obs	F-Statistic	Prob.
LELC does not Granger Cause LPGDP	150	3.15085	0.0458[b]
LPGDP does not Granger Cause LELC		1.62398	0.2007
LELT does not Granger Cause LPGDP	150	1.17151	0.3128
LPGDP does not Granger Cause LELT		1.33658	0.2660
LGCF does not Granger Cause LPGDP	150	3.03169	0.0513[b]
LPGDP does not Granger Cause LGCF		1.20485	0.3027
LLBR does not Granger Cause LPGDP	150	3.14887	0.0458[b]
LPGDP does not Granger Cause LLBR		14.6349	2.E−06
LOPN does not Granger Cause LPGDP	150	12.8975	7.E−06
LPGDP does not Granger Cause LOPN		0.41019	0.6643
LGDP_L1 does not Granger Cause LPGDP	150	4.65979	0.0109[a]
LPGDP does not Granger Cause LGDP_L1		2641.02	9E-115
LELT does not Granger Cause LELC	150	3.66919	0.0279[b]
LELC does not Granger Cause LELT		0.44056	0.6445
LGCF does not Granger Cause LELC	150	4.03379	0.0197[b]
LELC does not Granger Cause LGCF		0.62120	0.5387
LLBR does not Granger Cause LELC	150	2.94955	0.0555[c]
LELC does not Granger Cause LLBR		0.55961	0.5727
LOPN does not Granger Cause LELC	150	0.96487	0.3835
LELC does not Granger Cause LOPN		0.26742	0.7657
LGDP_L1 does not Granger Cause LELC	150	3.72240	0.0265[b]
LELC does not Granger Cause LGDP_L1		2.54726	0.0818[c]
LGCF does not Granger Cause LELT	150	1.05780	0.3499
LELT does not Granger Cause LGCF		1.32432	0.2692
LLBR does not Granger Cause LELT	150	2.89036	0.0588[b]
LELT does not Granger Cause LLBR		1.61837	0.2018
LOPN does not Granger Cause LELT	150	0.92967	0.3970
LELT does not Granger Cause LOPN		0.57178	0.5658
LGDP_L1 does not Granger Cause LELT	150	0.75897	0.4700
LELT does not Granger Cause LGDP_L1		3.24127	0.0420[b]
LLBR does not Granger Cause LGCF	150	1.36074	0.2597
LGCF does not Granger Cause LLBR		13.8329	3.E−06
LOPN does not Granger Cause LGCF	150	6.56667	0.0019[a]
LGCF does not Granger Cause LOPN		2.76597	0.0662[c]
LGDP_L1 does not Granger Cause LGCF	150	0.60441	0.5478
LGCF does not Granger Cause LGDP_L1		108.626	1.E−29
LOPN does not Granger Cause LLBR	150	11.9944	2.E−05
LLBR does not Granger Cause LOPN		0.93041	0.3967
LGDP_L1 does not Granger Cause LLBR	150	4.75492	0.0100[a]
LLBR does not Granger Cause LGDP_L1		5.18675	0.0067
LGDP_L1 does not Granger Cause LOPN	150	0.23515	0.7908
LOPN does not Granger Cause LGDP_L1		35.0040	4.E−13

*** significant at 1 % level of significance.
** significant at 5 % level of significance.
* significant at 10 % level of significance.
Source: Source: Author's analysis based on data from World Bank, International Energy Agency

Table 14
Dumitreschu-Hurlin Panel Causality tests.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LELC does not homogeneously cause LPGDP	5.483	3.120	0.002[a]
LPGDP does not homogeneously cause LELC	3.185	0.954	0.340
LELT does not homogeneously cause LPGDP	6.126	3.726	0.000[a]
LPGDP does not homogeneously cause LELT	3.702	1.441	0.150
LGCF does not homogeneously cause LPGDP	10.135	7.505	0.000[a]
LPGDP does not homogeneously cause LGCF	4.006	1.727	0.084[c]
LLBR does not homogeneously cause LPGDP	6.572	4.147	0.000[a]
LPGDP does not homogeneously cause LLBR	9.638	7.036	0.000[a]
LOPN does not homogeneously cause LPGDP	6.614	4.186	0.000[a]
LPGDP does not homogeneously cause LOPN	2.732	0.526	0.599
LGDP_L1 does not homogeneously cause LPGDP	6.177	3.774	0.0002[a]
LPGDP does not homogeneously cause LGDP_L1	57663.1	5436	0.0000[a]
LELT does not homogeneously cause LELC	3.4780	1.231	0.218
LELC does not homogeneously cause LELT	1.802	−0.351	0.726
LGCF does not homogeneously cause LELC	3.48504	1.236	0.216
LELC does not homogeneously cause LGCF	3.51919	1.268	0.205
LLBR does not homogeneously cause LELC	7.36314	4.891	0.000[a]
LELC does not homogeneously cause LLBR	6.81353	4.374	0.000[a]
LOPN does not homogeneously cause LELC	1.14126	−0.974	0.330
LELC does not homogeneously cause LOPN	4.80950	2.485	0.013[a]
LGDP_L1 does not homogeneously cause LELC	4.70548	2.387	0.017[a]
LELC does not homogeneously cause LGDP_L1	8.61792	6.075	0.000[a]
LGCF does not homogeneously cause LELT	3.73295	1.46973	0.142
LELT does not homogeneously cause LGCF	4.23706	1.94497	0.052[b]
LLBR does not homogeneously cause LELT	3.14040	0.91112	0.362
LELT does not homogeneously cause LLBR	3.45207	1.20495	0.228
LOPN does not homogeneously cause LELT	1.46368	−0.66955	0.503
LELT does not homogeneously cause LOPN	3.73168	1.46854	0.142
LGDP_L1 does not homogeneously cause LELT	2.46988	0.27902	0.780
LELT does not homogeneously cause LGDP_L1	5.36147	3.00497	0.003[a]
LLBR does not homogeneously cause LGCF	7.31198	4.84376	0.000[a]
LGCF does not homogeneously cause LLBR	7.80945	5.31273	0.000[a]
LOPN does not homogeneously cause LGCF	4.47629	2.17049	0.0300[b]
LGCF does not homogeneously cause LOPN	3.52280	1.27162	0.204
LGDP_L1 does not homogeneously cause LGCF	2.32873	0.14595	0.884
LGCF does not homogeneously cause LGDP_L1	129.214	119.763	0.0000[a]
LOPN does not homogeneously cause LLBR	6.73273	4.29768	0.000[a]
LLBR does not homogeneously cause LOPN	3.69759	1.43640	0.151
LGDP_L1 does not homogeneously cause LLBR	4.67195	2.35494	0.019[b]
LLBR does not homogeneously cause LGDP_L1	11.8997	9.16866	0.000[a]
LGDP_L1 does not homogeneously cause LOPN	3.29891	1.06055	0.289
LOPN does not homogeneously cause LGDP_L1	29.6160	25.8702	0.000

[a] Significant at 1 % level of significance.
[b] Significant at 5 % level of significance.
[c] Significant at 10 % level of significance.

previous studies [190,221]. Therefore, a long-run relationship exists between these two variables.

Investment in electricity infrastructure will increase the growth trajectory, as it will stimulate an increased uptake of electricity in the production process, thereby increasing the matrix of goods and services produced, and hence economic growth. This is in agreement with earlier studies like [15,253,254,231].

Increasing gross capital formation also leads to increase in the net electricity consumption. Economic growth leads to gross capital formation. An increase in GDP in these countries leads to more investment in capital goods, which leads to an increase in gross capital formation. The increase in capital goods is used to open up the industrial sector, which will ultimately lead to an increased matrix of goods and services in the country and, hence, economic growth [129].

There is a single-directional causal relationship between total labour force and electricity consumption, as well as real electricity trade. This can be explained by increased human capital development, leading to greater electricity consumption and a greater volume of electricity trade. This is in agreement with [233].

Similarly, there is a bidirectional causal relationship between trade openness and economic growth. Prosperity through increases in GDP leads to greater trade openness within the global community of interest to the study. A two-way causal relationship with feedback loops shows a sustained causation between the two variables of interest. The increased volume of goods and services produced locally will also increase the volume of exports hence greater economic growth within the region.

6. Conclusions and recommendations

This paper examines the dynamic causal relationship between electricity consumption and economic growth in East Africa for the period 1990 to 2021, It uses the dynamic ordinary least squares, fully modified ordinary least squares and the non-linear autoregressive distributed lag to establish the dynamic relation between variables of study. It is of great importance to examine electricity consumption as a clean energy source from the perspective of building regional energy markets and accelerating economic growth. This forms a sound pillar for making recommendations to both energy economists and policy authorities.

There is a unidirectional causal relationship running from GDP to electricity net consumption. This implies that electricity consumption significantly contributes to GDP in the long run. These economies need to consider investment in energy transition from traditional to modern energy sources, for which electricity consumption is the easiest and most suitable alternative. Therefore, moderate and heavy investments in

electricity generation, transmission, distribution, and consumption by end-users would yield greater economic growth for these countries [206]. East African countries are rich in energy resources, and they should invest in technologies that will expand their clean energy resources to allow for faster and sustained economic growth and development [255].

There should be deliberate efforts to increase financing in the electricity sector through provision of green bonds. This will help promote rapid growth with minimal adverse effects on the environment [256].

There should be increased investment in capital goods that drives industrial growth, as this has a substantial multiplier effect on net electricity consumption [130]. This would further trickle down all sectors and promote economic growth.

There should be an expansion of co-operant factors, especially the economic infrastructure that would match the increasing electricity growth. The improvement in transport infrastructure allows easy movement of both raw materials from source areas and finished goods to markets. Electricity facilitates the conversion of raw materials into finished goods, thereby promoting economic growth [257].

The growth hypothesis showing a unidirectional causal relationship running from electricity consumption to economic growth is perhaps due to an investment in electricity consumption which leads to an increase in production processes, which explains the increase in per capita GDP and hence economic growth and development. Consequently, an increase in electricity consumption leads to increased production in all sectors of the economy, which promotes economic growth. This increased consumption of electricity is counteracted by a policy that prioritizes investments in the electricity sector.

Policy makers should encourage multilateral efforts to invest in renewable energy development in the region [258]. Regional cooperation should focus on the development of renewable energy markets for public and private investment. The interaction between sector stakeholders could begin with sharing information across countries with respect to on-going projects, technologies, as well as financing and investment strategies. The establishment of partnerships between the public and private sectors would also facilitate the technology transfer process for bringing renewable energy projects to the market. Renewable electricity sources can foster economic growth and sustainable development.

Policymakers must also introduce appropriate incentive mechanisms for the development and market accessibility of renewable energy. Renewable energy provides a low carbon footprint. This contributes to low-carbon growth, which is in line with the current global development agenda. Such incentives could include tax credits and/or subsidies for the production and consumption of renewable energy. The establishment of markets for tradable renewable energy certificates along with the implementation of renewable energy portfolio standards may promote the expansion of the electricity subsector in specific and the renewable energy sector.

Therefore, this paper recommends that East African energy authorities not only develop energy policies geared towards expanding electricity infrastructure to increase electricity consumption, but also address efficient energy use to support economic growth. This would advocate for proper energy use and saving, where little returns are received. This would allow using it maximally where the returns are highest, which would promote economic growth in the long run.

This study has identified the need to analyse the electricity market pool within the East African Community. Since the greatest benefits that this region can harness are economic benefits that are evident by expanding energy markets as strategic investments decisions.

The major limitation of this study is the focusing on electricity consumption and economic growth in East Africa (1990–2021), and results hold true for the spatial and temporal context given, the study may not hold generalizability for a different time period or different region of study. Even when it provides useful findings, they may not hold for the entire African continent.

Secondly an emphasis on electricity investments in generation, distribution infrastructure, and consumption; however, the recent trend shows that electricity generation has exceeded the peak demand for both Uganda and Kenya. This leaves regional market integration with operational gaps and therefore calls for greater inquiry into how best this can be promoted.

The use of the Granger causality test has a limitation in establishing a definitive causality, here we implored the use of the Dumitreschu-Hurlin (2012). These shortcomings called for the use of multi-model approach to mitigate weaknesses of one model by a more robust one.

Another limitation is the size and quality of the grid in East African countries. Even with the possibility of cross border electricity trading there is no guarantee of perfect main grid in these countries more research is still needed to harmoniously allow its effective implementation and achieve rapid economic growth.

The other area of further research is the operationalisation of energy market through better institutions and good governance, within the East African community, real electricity trade is not related to GDP. This needs to be further investigated in other developing areas such as Sub-Saharan Africa.

Ethical approval

This study never involved human subjects and got ethical clearance from relevant authorities.

Consent to participate

Since no human subjects were involved, there was no need for consent from participants.

Consent to publish

This work has not been presented to a publishing house before and upon acceptance by this journal and will relinquish the consent to publish.

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CRediT authorship contribution statement

Geoffrey Ssebabi Mutumba: Idea conception, Introduction and literature, Discussion, Conclusion. **Geoffrey Mubiinzi:** Methodology, findings. **David Amonya:** Formal analysis.

Declaration of competing interest

For possible publication in your esteemed Journal. I confirm that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere. I hereby declare no conflict of interest.Furthermore, I confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Data availability

Data will be made available on request.

Appendix

Table 13
Johansen Fisher Panel Cointegration Test

Hypothesized No. Of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	284.9	0.0000	188.9	0.0000
At most 1	136.4	0.0000	58.15	0.0000
At most 2	87.70	0.0000	42.25	0.0000
At most 3	54.14	0.0000	34.99	0.0001
At most 4	28.29	0.0016	16.51	0.0860
At most 5	21.43	0.0183	22.88	0.0112
At most 6	5.550	0.8516	5.550	0.8516
Individual cross section results				
	Trace Test		Max-Eign Test	
Cross Section	Statistics	Prob.**	Statistics	Prob.**
Hypothesis of no cointegration				
Uganda	271.9030	0.0000	140.1676	0.0000
Tanzania	244.8768	0.0000	106.1378	0.0000
Kenya	197.2964	0.0000	64.3217	0.0001
Burundi	240.1914	0.0000	131.9862	0.0000
Rwanda	207.9723	0.0000	74.6827	0.0000
Hypothesis of at most 1 cointegration relationship				
Uganda	131.7354	0.0000	53.8970	0.0002
Tanzania	138.7390	0.0000	43.2244	0.0074
Kenya	132.9747	0.0000	42.8974	0.0081
Burundi	108.2052	0.0003	46.9381	0.0023
Rwanda	133.2896	0.0000	42.8543	0.0083
Hypothesis of at most 2 cointegration relationship				
Uganda	77.8384	0.0008	28.4714	0.0863
Tanzania	95.5146	0.0000	37.5255	0.0056
Kenya	90.0773	0.0000	35.9244	0.0094
Burundi	61.2671	0.0394	29.5989	0.0634
Rwanda	90.4352	0.0000	40.0853	0.0023
Hypothesis of at most 3 cointegration relationship				
Uganda	49.3670	0.0046	26.4620	0.0240
Tanzania	57.9891	0.0003	29.1043	0.0098
Kenya	54.1529	0.0011	26.7475	0.0219
Burundi	31.6682	0.2735	15.8127	0.4374
Rwanda	50.3499	0.0035	28.7433	0.0112
Hypothesis of at most 4 cointegration relationship				
Uganda	22.9050	0.0737	14.5545	0.1441
Tanzania	28.8848	0.0122	14.9873	0.1260
Kenya	27.4054	0.0195	13.8496	0.1781
Burundi	15.8555	0.3901	10.2087	0.4635
Rwanda	21.6066	0.1046	13.9357	0.1736
Hypothesis of at most 5 cointegration relationship				
Uganda	8.3505	0.2108	7.9862	0.1753
Tanzania	13.8975	0.0270	12.0506	0.0357
Kenya	13.5558	0.0309	13.2620	0.0216
Burundi	5.6467	0.4804	5.5513	0.4036
Rwanda	7.6709	0.2633	7.6676	0.1968
Hypothesis of at most 6 cointegration relationship				
Uganda	0.3644	0.6091	0.3644	0.6091
Tanzania	1.8469	0.2049	1.8469	0.2049
Kenya	0.2938	0.6491	0.2938	0.6491
Burundi	0.0954	0.7995	0.0954	0.7995
Rwanda	0.0033	0.9627	0.0033	0.9627

**MacKinnon-Haug-Michelis (1999) p-values.

Table 14
Wald test for short run Causality

Null Hypothesis: C (1) = 0,C (2) = 0,C (3) = 0,C (4) = 0,C (5) = 0,C (6) = 0				
Normalized Restriction (=0)	Value	Std. Err.	t-statistic	Prob.
C (1)	0.035146	0.010573	3.324232[a]	0.00110
C (2)	0.174693	0.100449	1.739119	0.08420
C (3)	0.098161	0.009322	10.529650[a]	0.00000
C (4)	0.236081	0.030013	7.865913[a]	0.00000
C (5)	−0.070251	0.011989	−5.859574[a]	0.00000
C (6)	0.731251	0.027281	26.803950[a]	0.00000

Source: Source: Author's analysis based on data from World Bank, International Energy Agency

[a] Significant at 99 % confidence level and restrictions are linear in coefficients.

The power market allows sale of power from low-cost to high cost market to allow efficient utilization. This accelerates power uptake and economic growth. The East African Electricity market integration has made efforts through the East African Power Pool (EAPP), which began.

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