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Research article

Empirical assessment of drivers of electricity prices in East Africa: Panel data experience of Rwanda, Uganda, Tanzania, Burundi, and Kenya

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Abstract: Sustainable electricity supply plays a key role in economic development. Cost recovery, profitability and affordability of electricity through power tariff regulation, have become a subject of conflict between private providers and regulators. Consequently, regulators need to balance the interests of all stakeholders. The objective of this study, is to measure to which extent, Electricity Net Consumption (EC), Electricity Net Generation (EG), electricity transmission and distribution losses (Losses), International Average Crude oil prices (FP), Consumer Price Index (CPI), Industry Value Added (IVA) could influence the Average Electricity Prices (EP) in East Africa, especially in Rwanda, Uganda, Tanzania, Burundi, and Kenya. The data are from World Bank Indicators and cover the period from 2000 to 2019. This study adopts a three-stage approach, consisting of panel unit root tests, panel cointegration tests and estimating the long run cointegration relationship of the variables in a panel context. We applied four different panel unit root tests including ADF-Fisher Chi-square, Levin, Lin and Chu (LLC); PP-Fisher Chi-square, and Im, Pesaran, and Shin, (IPS). The results reveal that the variables are non-stationary at "level", stationary at first-differences and integrated with order one denoted as I(1). The Pedroni, Kao and Johansen Fisher co-integration tests were performed. This study uses full modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) to estimate the long run relationship among the variables. We find that the increase in EG, FP, and CPI increase the Average Electricity Prices (EP); while the increase in Losses, EC, and IVA decreases EP. Therefore, we recommend the promotion of long-term investment policies in renewable sources and efficient policies to reduce technical and commercial losses. In addition, this study suggests that appropriate policies related to subsidized electricity prices would, however, prevent adverse effects related to inefficient over-consumption of electricity.

Keywords: electricity prices; electricity consumption; electricity generation; cointegration; stationary; transmission losses; East Africa; Panel Data

1. Introduction

Electricity supply plays a key role in the economy, both as an essential service to customers and as an intermediate input into other industries [1]. Before the first oil shock, the energy sector had a supply-oriented focus where the objective was to meet a given exogenous energy demand by expanding the supply. Since the early 1970s, the energy sector has caught the attention of policymakers because of sudden price increases. Since then, energy research has grown significantly in size [2]. Energy models were however not developed for the same purpose. Some were concerned with better energy supply system design given a level of demand forecast, a better understanding of the present and future demand-supply interactions, energy and environment interactions, energy-economy interactions, and energy system planning [3]. The electricity industry has undergone significant changes in many countries since the 1990s and industrial operations and decision-making has changed from the state-dominated planned style to private-oriented decisions. Often the introduction of these structural changes made the decision-making more complex [3]. However, these changes happen generally in developed countries, and in developing countries, the electricity industry is generally still state-dominated.

In developing countries, the investments in the production and supply of electricity are almost done by the government budget where the private investments are still very low. Due to this situation, electricity markets behave as monopoly markets where there is one or very few sellers to many buyers. To meet the increasing demand, developing economies are more and more inviting private operators to invest in electricity production. This trend is likely to change their electricity market structure from monopoly markets to competitive markets. In a competitive market, the seller and the buyer are all price takers and the market forces influence the price. Electricity is now treated as a commodity worldwide, which can be bought, sold, and traded at market rates like any other commodity. Electricity as a commodity is probably the most important man-made commodity which is different from other commodities because it cannot be stored economically and has to be consumed whenever it is produced [4].

In a competitive market model, consumers maximize their utility subject to their budget constraints and producers maximize their profits subject to the constraints of production possibilities. In general, the demand for a good reduces as prices rise (i.e., inverse relationship with price) and vice versa. Similarly, producers face an upward sloping supply curve which implies that the higher the price, the more the supply, as at higher prices more producers become viable. In a competitive market, the interaction of supply and demand decides the market clearing price of the good and the quantity of goods that will be sold or purchased [3]. However, given the special characteristic of the non-storability of electricity, the supply of electricity is inelastic in short term. This implies that the supply of electricity could affect the change in electricity price in the short-term period, as well as in the long term, since the increase in electricity prices will attract new investors in the electricity sector and increase the production capacity, to increase the supply.

In developed countries, the electricity market deregulation has been implemented as an effective measure that addresses the energy supply and demand transactions in a commodity market platform. This has provided them with the competitive market model characteristics where the consumers have the autonomy to select their electricity provider. Still, the electricity market liberalization is a long- and complex-term process requiring several market reforms, financial and human skills means which are not sufficient in developing countries [5]. This is a challenge to most of developing countries to undertake these reforms. Therefore, like most other commodity markets, electricity pricing in developed countries like USA and European countries is mainly driven by supply and demand [6]. This implies that the electricity market in developing countries behaves as a monopoly market while in developed countries, behaves as a competitive market. This difference in market structure affects the electricity pricing mechanisms in both blocks of countries. In addition, the difference in electricity generation technologies and sources plays also a key role in variations of drivers of electricity prices.

Despite ambitious targets to increase renewables penetration in electricity production, the natural gas and nuclear energy are still the leading source of electricity generation in developed countries while fossil fuels are still leading in developing countries [7–10]. In order to mitigate the negative impacts of fossil fuels on the environment, many countries have embraced the renewable energy agenda. In 2000, the German share of renewables was only 6%, while in 2021 it reached 41% [11]. The increasing share of renewables has been accompanied by decreasing day-ahead electricity prices. The prices dropped from 51 €/MWh in 2011–29 €/MWh in 2016 [12]. Besides that, given the high dependence of wind and solar power generation on weather factors, their intermittency tend to increase electricity spot price volatility in the absence of viable electricity storage [12]. However, as nuclear, coal, and oil-fired electricity generation slows, there is an increased reliance on natural gas-fired generators. At about 38.4%, natural gas was the largest source of US electricity generation in 2021 [13].

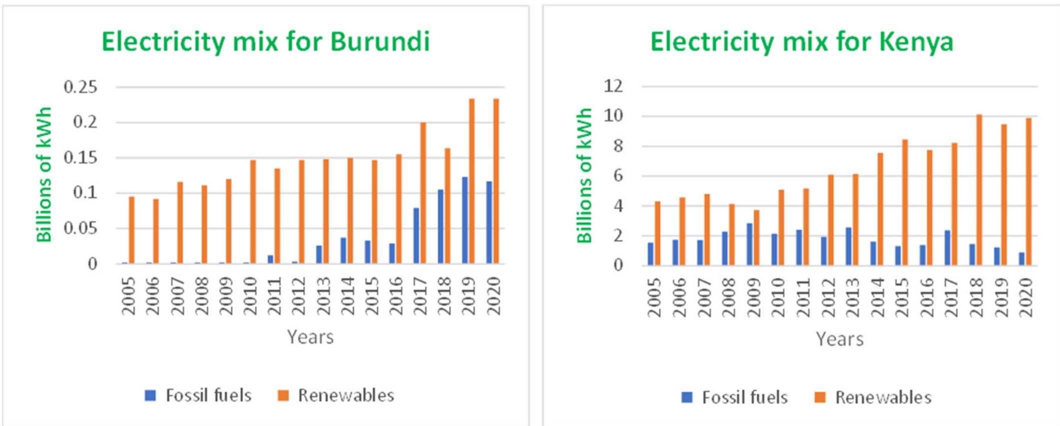

Figure 1. Electricity mix for Burundi and Kenya.

Concerning East African Countries under study, the electricity generation capacity has significantly increased as indicated by the Figures 1–4. In Burundi the electricity net generation increased from 97 million kWh in 2005 to 350 million kWh in 2020 while for Kenya, it increased from 5,862 million kWh in 2005 to 10,792 million kWh in 2020. For Rwanda, it increased from

113 million kWh in 2005 to 1,059 million kWh in 2019 while for Tanzania, it increased from 3,430 million kWh in 2005 to 7,176 million kWh in 2020 and Uganda, it increased from 1,953 million kWh in 2005 to 4,665 million kWh in 2020.

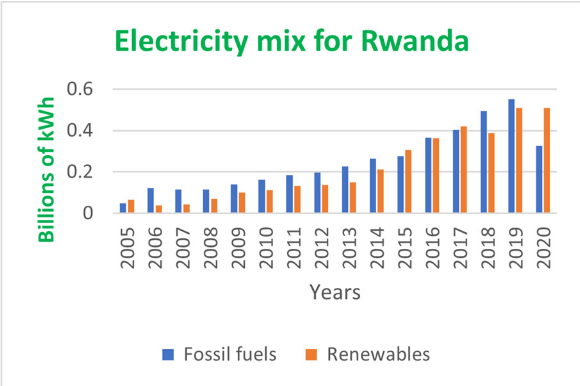

Figure 2. Electricity mix for Rwanda.

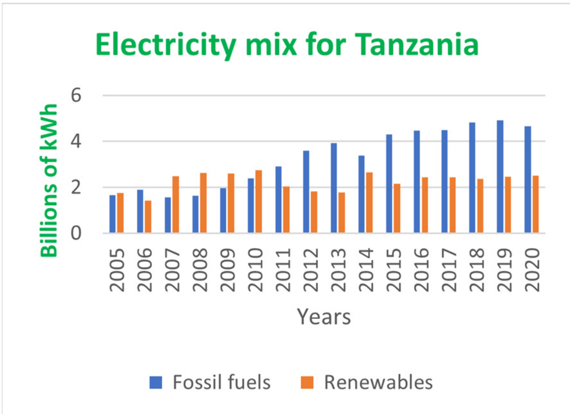

Figure 3. Electricity mix for Tanzania.

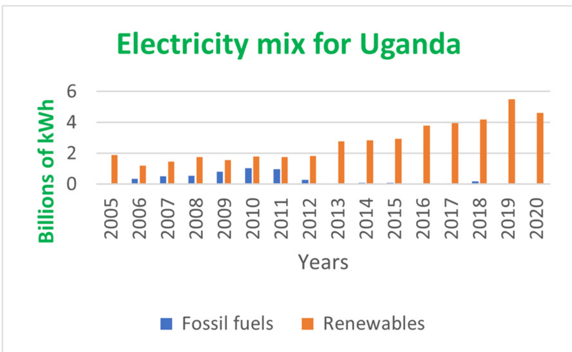

Figure 4. Electricity mix for Uganda.

Note: Authors' own elaboration with data retrieved from World Bank data, (2022): http://www.doingbusiness.org/methodology.

Despite the increase in electricity generation, as indicated by the Figure 5, the electricity prices slightly reduced in some countries like Rwanda, Uganda and Tanzania from 2016 and slightly increased for Kenya and Burundi for the same period. On one hand, a common characteristic of electricity generation in Kenya and Burundi where electricity prices have increased, is that their electricity mix sources were mostly dominated by renewables under the period of the study. In Burundi renewable resources produced 97% in 2005 and 67% in 2020 of the total generated electricity while in Kenya, it was 74% in 2005 and 92% in 2020. On the other hand, concerning Rwanda and Tanzania, it was 58% and 48% for Rwanda and 51% and 35% for Tanzania respectively in 2005 and 2020. While the increase in electricity prices in Kenya and Burundi follows the increase in electricity generation from renewable sources, in Uganda, the reduction in electricity prices follows, the increase in renewable sources for electricity generation.

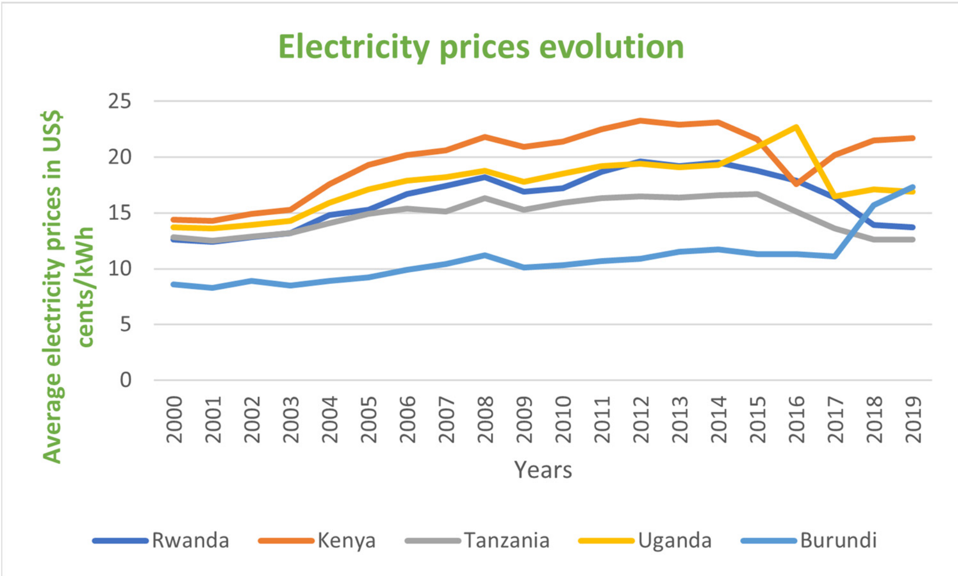

Figure 5. Evolution of average electricity prices.

Note: Authors' own elaboration with data retrieved from World Bank data, (2022): http://www.doingbusiness.org/methodology.

In developing countries, electricity prices are not volatile as it is in liberalized market of developed countries. These prices could be fixed in the short term, but in long term, prices could change following the change in the cost of supplying electricity. Natural, technological, market, and regulatory factors affect the cost of supplying electricity [1]. These include operating environment, production economies, energy losses as well as government interventions and regulatory decisions, which all affect the total environment in which each power utility operates. However, given the key role of electricity in the socio-economic development of any country, governments have established regulatory authorities to control electricity prices and monitor the operations of the utilities. The mission of regulatory authorities includes among others, protecting the rights of consumers, balancing the interests of all stakeholders, ensure cost reflective but affordable prices and delivery of quality services to all.

Electricity production, transmission and distribution involve huge long-term investments. Therefore, economic operators in the electricity sector need to ensure that they are able to recover their investment cost plus a reasonable rate of return, as approved by the regulator. While developing economies, especially East African countries are inviting private operators to invest in the electricity sector, the market is generally still behaving as a monopoly type. It is in this context that, cost recovery and affordability of electricity through electricity tariff setting, have become a subject of conflict between electricity providers and regulators. On one hand, electricity providers expect a tariff that covers all costs related to electricity production, transmission and distribution as well as earn a positive return on their investments. On the other hand, regulatory authorities seek to balance positive returns on investments and the socio-economic well-being of the population through tariff signals [14]. Therefore, in the context of balancing the interests of all stakeholders and transparency, policymakers, regulatory authorities, as well as investors should be aware of the main macroeconomic, investment, operational, and demographic factors that affect electricity prices.

1.1. Research objective

The objective of this study, is to conduct a panel data analysis of five East African countries to measure to which extent, Electricity Net Consumption (EC), Electricity Net Generation (EG), electricity transmission and distribution losses (Losses), International Average Crude oil prices (FP), Consumer Price Index (CPI), Industry value added (IVA) could influence the electricity prices (EP). In addition, a comparative analysis will be conducted between Rwanda, Kenya, Uganda, Burundi, and Tanzania. This study was particularly motivated by the fact that no similar research has been conducted in this area for the electricity-regulated markets in East Africa, based on the literature review. The novelty of the study resides in the macroeconomic and operational variables considered, location of the study, and the applied panel data model. The remainder of the study is organized as follows: section 2 presents the literature review, section 3 explores Econometric model, data, and methods, section 4 shows and discusses the results, and section 6 provides conclusions and policy recommendations.

2. Literature review

Most of the studies related to “drivers of electricity prices” have been conducted in developed countries with liberalized or deregulated electricity markets. Most of these countries produce more electricity than they consume from advanced technologies such as nuclear. For environment purposes, developed countries are slowing nuclear, coal, and oil-fired electricity generation. However, there is an increased reliance on natural gas-fired generators in developed countries. In addition, there are several electricity producers in these countries at low cost due to their advanced technologies and advanced human skills. This implies that the main drives of electricity prices in developed countries are the interaction between supply and demand for electricity as well as the natural gas market [12,15]. As indicated in the Figures 1–4, developing countries like East African countries are still abundantly using oil-fired electricity generation and hydropower and the cost of electricity supply is still very high. The electricity market structure in both block of countries is practically different. Therefore, the fundamental drivers of electricity prices in developed countries are different from those of developing countries especially East Africa without such potentials.

The literature agrees that the price of electricity depends on fundamental factors, demand and supply of electricity, power systems, and strategic factors. Girish [4] argues that in a competitive electricity market, factors influencing electricity prices can be the price of fuel, weather conditions, time indices, and the cost of production of electricity per unit. Ruksans et al. [16], in the analysis of factors that affect electricity prices in Baltic Countries, used an econometric model where the dependent variable is the price of electricity. They point out that, Fuel prices (coal, gas, oil); political decisions (for example shutdown of German nuclear), Natural disasters (for example tsunami in Japan), power plant operation, transmission capacity restriction, and flood time for countries depending on hydropower plants like Norway and Sweden, have a great influence on the amount of produced electricity and therefore on electricity price. This implies that weather conditions affect electricity net consumption and generation which in turn affect electricity prices.

Uribe et al. [7] investigated the transmission of natural gas shocks to electricity prices under different scenarios of electricity generation for 21 European markets. They found that the level of market integration is the main factor underlying national differentiation. Denmark, Finland, Sweden, and Germany were showed to be the most vulnerable markets to natural gas price shocks under distress. Moreover, Spain, Italy, Portugal, and Norway presented the lowest vulnerability indicators. However, Mosquera-López & Nursimulu [12] assessed the drivers of electricity price dynamics in German electricity market. They found that short-run and medium/long-run price drivers differ and, more importantly, that they vary over time. In the case of the spot market, the determinants of prices are renewable infeed and electricity demand, while in the futures market the main drivers are natural gas, coal and carbon prices. This is in line with the study of Gil-Alana et al. [15] that found a close relation between energy consumption and energy prices in Spain and Portugal. In addition, they highlighted that against the backdrop of numerous evidence the variable renewable generation decreases electricity prices and increases price volatility. This result related to the influence of renewables, corroborate with many recent findings such as of Sirin and Yilmaz [17]. They assessed the effects of the variable renewable energy technologies (wind and run-of-river hydro) on Turkish balancing market prices. Their model results show that system marginal price declines as variable renewable energy generation increases. Moreover, there is a higher probability of positive imbalance as the positive difference between real-time and projected variable renewable energy generation increases. They conclude that, an increase in variable renewable energy generation implies lower prices, but higher positive imbalances for the system.

Contrary to developing countries, in most developed countries the electricity is traded on electric power exchange spot market like other commodities. Saad Suliman & Farzaneh [5] conducted a study on pricing and energy policy regulations in Japan electric power exchange spot market. From their results, a one GWh addition from nuclear, hydroelectric, geothermal, biomass, solar, or wind power production technologies decreases spot prices. Contrarily, adding one GWh from thermal, hydroelectric storage, or regional interconnections raises the spot prices. While most studies related to drivers of electricity prices in developed countries ignore macroeconomic variables, Foroni et al. [18] included them in their empirical study, to analyze the importance of macroeconomic information, for forecasting daily electricity prices in two of the main European markets, Germany and Italy. They reach on the conclusion that industrial production index and oil price are more important for short horizons than for longer horizons pricing. The fundamental drivers of electricity price in competitive markets were also assessed by Afanasyev et al. [10]. Their obtained results show that the influence of electricity demand is most prominent both in the short and long terms for Europe-Ural price area (ATS

EU) market and APX power spot exchange in the UK. However, for the Siberia price area (ATS SI), its impact is significant only in the long term. Finally, for all the electricity exchanges under their study, the influence of fuel markets was absent in the short term and became prominent only in the medium or long terms.

Based on the literature, it is clear that in competitive markets, the price of electricity is mostly set by the interaction of supply and demand for electricity, renewable energy technologies as well as natural gas market. In developing countries however, there is a limited competition in the electricity market, the price of electricity is generally determined by operational, demographic and macroeconomic factors. Luis et al. [19] conducted a fractional integration and cointegration study of several Kenyan electricity price series. After examining which factors that might be behind the electricity price movements in Kenya, they noted that the Consumer Price Index (inflation), oil prices, and interest rate all have positive and significant effects on the electricity prices. Even though, they noted that both demand and supply side shocks have historically influenced electricity prices in Kenya. Demand side shocks arise from high demand for electricity in years of higher production associated with higher growth rates of critical sectors such as manufacturing that rely heavily on electricity as an input into the production process. They also arise from higher consumer demand associated with an increasing population.

Most developing countries, use mainly off-grid electricity such as solar or biogas in rural areas and on-grid electricity in urban areas. Therefore, it seems that it is the increase in population and access to electricity in urban zones which could significantly affect electricity consumption and hence its prices. However, Kwakwa and Aboagye [20] investigated the impact of growth, industrialization, urbanization, and trade openness on the energy consumption in Ghana, and they found that in the short run the increase in urbanization (measured as the annual growth rate of the urban population) did not significantly affect the consumption of electricity, while in long run, the urbanization increased energy consumption. Li et al. [21] in their study explores the intrinsic relationship among urbanization, industrialization, and energy security, as well as the influencing mechanisms of urbanization and industrialization on energy efficiency using a fixed effect model. They conclude that, while energy security level decreases considerably with the rise of energy consumption and population growth, the increase in urbanization and industrialization levels can increase energy security through energy efficiency improvements. This can be explained by the fact that urbanization can reduce electricity distribution and transmission losses and hereafter the cost of electricity supply. In addition, regional industrialization creates a competitive spirit among industries, and to reduce the industrial cost of production, they tend to use new technology which requires less energy and with a high-power factor which implies lower line losses.

Some of the literature suggests that high economic growth rates (GDP) increase the demand for electricity and in turn have an impact on electricity prices. Mabea [22] investigates the relationship between Kenya's electricity consumption, real disposable income, and residential electricity prices. In his research, he employed the Engle and Granger two-step procedure and error correction model for a time series from the period 1980 to 2009 to analyze electricity demand. The results of the analysis show that as Kenya achieves higher GDP growth rates, electricity requirements rise and conclude that this has a potential implication for electricity prices. This positive relationship between economic growth and electricity demand has been evidenced by many other scholars [23–30].

Mumo et al. [31], combine operational factors and macroeconomic factors in their model when seeking to determine the best tariff model that can be used in Kenya to improve electricity consumption.

Their study explored all the factors, which affect the cost of electrical energy. They find that the price of electricity (tariff) is mainly determined by fuel prices, economic factors such as inflation and the purchasing power of the consumers, capital cost as well as operational costs. Besides that, the Kenya Institute for Public Policy Research and Analysis (KIPPRA) [32] in their comprehensive study and analysis of energy consumption patterns in Kenya concludes that the fuel and exchange rate costs affect the electricity prices in Kenya and highlighted that the Tariff Adjustment Factor applicable in each quarter comprises of the Fuel Adjustment Factor, Exchange Rate Adjustment Factor as well as Inflation Rate Adjustment Factor. This is because, in most developing countries, thermal energy plays an important role in the production of electricity. This implies that the price of fuel on the international market, the exchange rate, and the country's inflation rate could affect the cost of production and hence the electricity prices in the national currency.

Electricity Regulatory Authority of Uganda (ERA) [33], in their electricity tariff quarterly adjustment methodology of January 2018, pointed out that, the price of electricity depends on the base tariff which is set taking into account the power utilities' Revenue Requirements, which is the amount of revenue that a company requires to meet its regulated costs. They indicated that the annual Base Tariff should be adjusted at the beginning of each calendar year to take into account changes in other tariff parameters such as electricity losses, collection rates, operations and maintenance costs, and investment costs. In setting the base tariff, they also took into account macroeconomic factors such as the Exchange rate, CPI (Inflation), US producer price index, and international price of fuel (US$ per barrel). Although the Base Tariffs are expected to remain constant throughout the calendar year, the macroeconomic parameters used in the determination of the Base Tariffs are not kept constant necessitating a need for applying the adjustment Factors.

Donna and Poudineh [34] also pointed out that in Tanzania, the Energy and Water Utility Regulatory Authority (EWURA) determines the electricity price (Tariff) based on TANESCO's (the power utility's) operating expenses, financial costs, and other operating income (including government subsidy), depreciation and TANESCO's Capital Investment Plan (CIP). Besides that, TANESCO has requested that a tariff indexation mechanism have to be used to adjust changes in costs that are outside of TANESCO's control so that the tariff revenue is kept at pace with rising costs during periods between formal reviews. Local inflation and foreign exchange rate fluctuation adjustments based on Bank of Tanzania data are also proposed, along with the indexation of fuel costs.

Dragasevic et al. [35] in their analysis of the factors influencing the formation of the price of electricity in the deregulated markets of developing countries, found that network capacity utilization and losses in the transmission system, do not have a significant impact on the price of electricity because the loss was only 2%. They also pointed out that the increase in the number of consumers in the system leads to an increase in the cost of distribution capacity utilization and has a greater impact on the price of electricity. In addition, they noted that an increase in the generated amount of electricity, and a small increase in the price of electricity occurs because there is still one large electricity producer in the market, which, despite the deregulation of the market, has a significant monopoly and consequently power.

In fact, the electricity supply cost and prices are influenced by internal and external factors. Internal factors such as productive efficiency are under the control of management and external factors are those that the industry has no control such as the price of fuel or inflation. As reliable supply and efficient pricing contribute to overall economic performance, in delivering electricity many factors must be taken into account, including those that are out of the control of the service providers [1]. This study combines external and internal factors considered in the panel data model for five countries in the East African region. From the literature review, no such empirical work has yet been conducted for East African countries using panel data.

3. Econometric model, data, and methods

3.1. Definition of econometric variables

This research used econometric panel data from five East African Countries, Rwanda, Uganda, Kenya, Tanzania, and Burundi. The dataset is based on yearly observations from 2000 to 2019. The data on Average Electricity Prices (EP), Electricity Net Generation (EG), and Electricity Generation mix was downloaded on 16 June 2022 from http://www.doingbusiness.org/methodology (World Bank). The data on Industry value added (IVA) and Consumer Price Index (CPI) was downloaded on July 20, 2022 from World Bank Development Indicators of World Bank (WDI). Moreover, the data on International Average Crude oil prices (FP) was downloaded on July 05, 2022 from World Bank Commodity Price Data (The Pink Sheet). Finally, the data on Electricity Transmission and Distribution losses (Losses) and Electricity Net Consumption (EC) was downloaded on 16 June 2022 from World Bank portal https://www.worldbank.org/en/programs/business-enabling-environment. The used software for estimations is E-views 12.

3.1.1. Dependent variable

3.1.1.1. Average end-user electricity prices (EP)

Electricity as an essential service to customers and as an intermediate input into other industries, it plays a vital role in the development of any country. This is the reason why most countries have established regulatory authorities to monitor the performance of power utilities and undertake price regulation. Contrarily to developed countries where the electricity market is liberalized and the electricity price is set by the market forces[10,12,36], in developing countries electricity tariff is set by utility regulatory authorities. The electricity tariff design must meet two main objectives including, to generate the needed money to cover the efficient costs of the activities of the utility [37] as well as sending the right economic signals to each customer to ensure optimal socio-economic use of electricity [38]. The literature on electricity pricing [25–33] suggests different factors that can be taken into account when determining electricity prices. These include internal factors that are under the control of the power utility on one hand, and on the other hand, there are external factors that are beyond the control of the utility company. However, most of the literature agrees that the level of electricity generation, consumption, electricity generation mix technologies, transmission, and distribution losses, macroeconomic factors as well as fuel prices have a great impact on electricity prices. In electricity tariff design, customers are categorized and each category experience different tariff based on time of use and other factors such as load factor, consumer uptake voltage level and level of consumption. Therefore, this research uses average electricity prices as computed by the World Bank through doing business project and take into account only commercial and industrial customers' electricity tariffs. Figure 5 shows the graphical representation of the evolution average electricity prices in countries and period under study.

Table 1. Variables, data measurement, and source.

Variable	Abbreviation	Measurement	Data source
Average electricity prices	EP	US cents per kilowatt-hour (kWh)	http://www.doingbusiness.org/methodology (World Bank) and country regulatory authorities report.
Electricity net generation	EG	kWh	http://www.doingbusiness.org/methodology (World Bank)
Electricity transmission and distribution losses	Losses	kWh	https://www.worldbank.org/en/programs/business-enabling-environment (World Bank)
Electricity net consumption	EC	kWh	https://www.worldbank.org/en/programs/business-enabling-environment (World Bank)
International average crude oil prices	FP	US$/Barrel	World Bank Commodity Price Data (The Pink Sheet)
Industry value added	IVA	US$	World Bank Development Indicators, 2022
Consumer price index	CPI	-	World Bank Development Indicators, 2022

3.1.2. Independent variables

3.1.2.1. Electricity net generation (EG)

Generation data consist of both utility and non-utility sources from electricity, combined heat and power plants. Electricity net generation excludes the energy consumed by the generating units. There are economies of scale in electricity generation. This is attributed to lesser leakages and power losses obtained in larger generating units as well as operating and maintenance costs that increase less than proportionally with power plant unit size [1]. Due to the insufficiency of financial and human resource means, most developing countries develop electricity generating units that are not large enough to benefit from the economies of scale of generating units. This could affect the electricity cost of production and price. However, developed and developing countries mostly experience two different scenarios. Based on the non-storable and continuous consumption characteristics of electricity, generators are required to match supply to demand in real-time. To handle short-term peak loads, generally developed countries use the excess capacity of their baseload generators with low supply costs while developing countries use quick-start generators with high supply costs. Consequently, the increase in electricity demand could affect electricity prices in developed and developing countries in different ways. Figure 6 describes the evolution of the variable Electricity Net Generation.

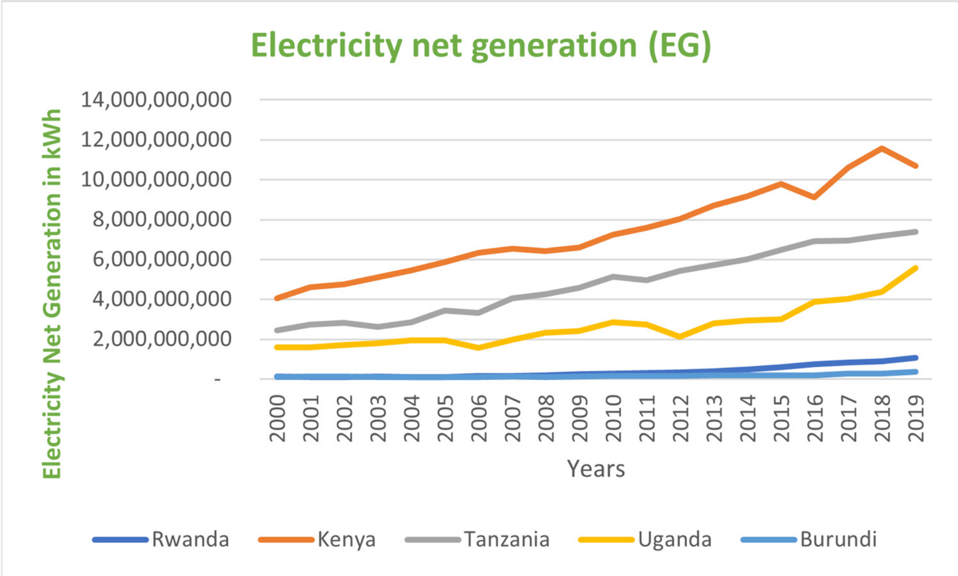

Figure 6. Evolution of electricity net generation.

3.1.2.2. Electricity net consumption (EC)

Total electric power consumption consists of total net electricity generation combined with electricity imports subtracting electricity exports and electricity transmission and distribution losses. However, some countries in East Africa, consume more electricity than they generate due to electricity imports. Figure 7 describes the evolution of the variable Electricity Net Consumption.

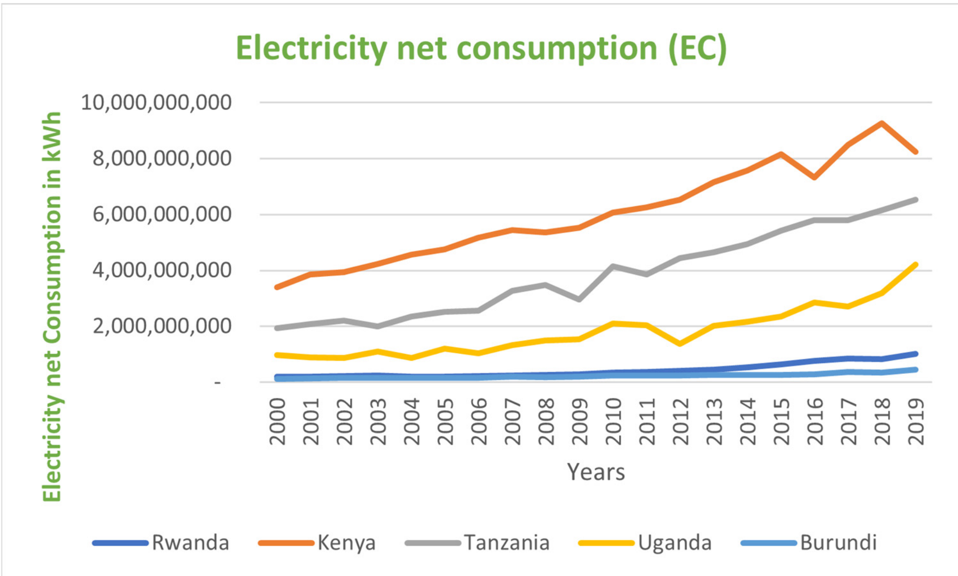

Figure 7. Evolution of electricity net consumption.

3.1.2.3. Electricity transmission and distribution losses (Losses)

Transmission and distribution losses are fundamentally linked to the electricity supply network configuration, with their size depending upon voltage delivered and line or network resistance encountered in delivery. The number of customers, length of distribution line, locational, and physical factors all contribute to resistance in delivering electricity to final customers [1]. Low customer densities can increase losses because longer lengths of distribution lines that must be used. Therefore, losses are at lower levels in the predominantly urban networks. This is because urban networks have lower levels of resistance in delivering electricity over shorter distances. Dragasevic et al. [35] like most of the literature [1,10] agree that electricity transmission and distribution losses affect electricity production cost and hereafter prices. Figure 8 describes the evolution of the variable Electricity Transmission and Distribution losses.

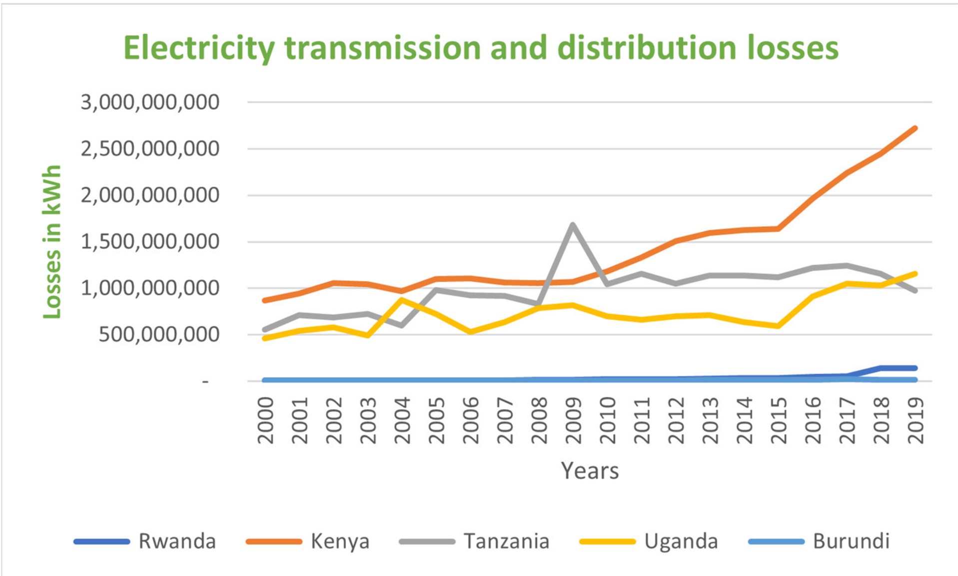

Figure 8. Evolution of transmission and distribution losses.

3.1.2.4. International average crude oil prices (FP)

Data on International Average Crude oil prices are expressed in real and nominal terms. The nominal value of any economic statistic is measured in terms of actual prices that exist at the time. The real value refers to the same statistic after it has been adjusted for inflation. For this study, we used oil prices in real terms. The price is expressed in $/bbl. where the abbreviation bbl. refers to a barrel of crude oil. The data has been extracted from World Bank Commodity Price Data (The Pink Sheet) (2022) and Energy Intelligence Group (EIG). Figure 9 describes the evolution of the variable international average crude oil prices.

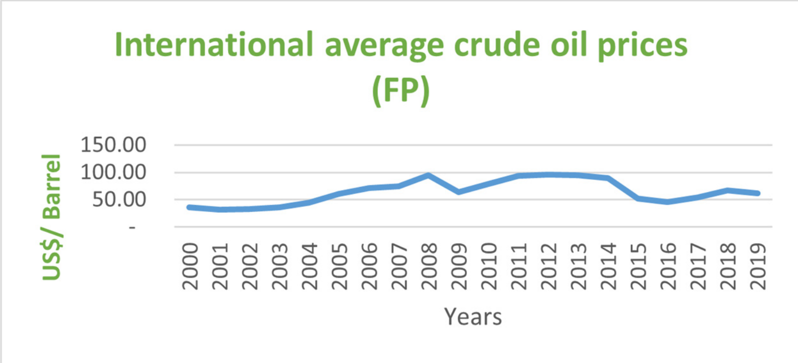

Figure 9. Evolution of international average crude oil prices.

3.1.2.5. Industry value added (IVA)

According to World Development Indicators, Industry value added (IVA) comprises value added in mining, manufacturing, construction, electricity, water, and gas. This is the net output of a sector after adding up all outputs and subtracting intermediate inputs. Data are in constant 2015 prices, expressed in U.S. dollars. One of the economic characteristics of the electricity supply is its capital intensiveness. Therefore, the investments if not well-planned can result in stranded assets and with a very high proportion of fixed assets. Due to this reason, economies of density and output in distribution can affect electricity cost of production. This implies that the average cost of servicing a particular area declines as the number of customers in that area using existing assets increases, or as the average load drawn by those customers increases [1].

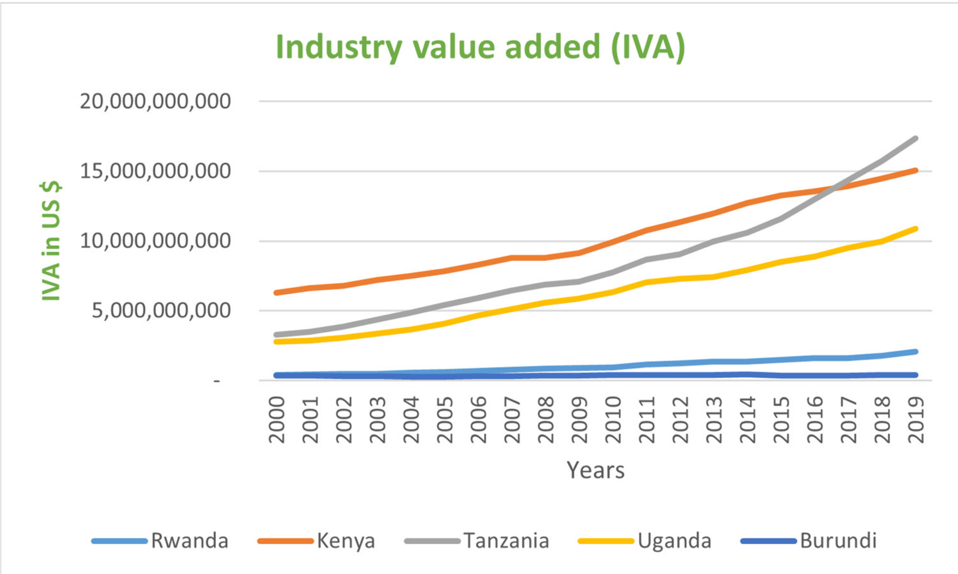

Figure 10. Evolution of Industry value added.

It is also obvious to note that the industrialization of any country requires more and more electricity as an input in the production process. However, Dan [47] notes that there has been a gradual decline in energy consumption in China since 1978 despite increasing industrial growth and attributed this to energy efficiency. After the oil price shocks in 1973/74 and 1979/80, average productivity in energy use increased due partly to the replacement of energy-inefficient capital with efficient ones [48]. This indicates that industrial growth in developed countries following the replacement of energy-inefficient capital with efficient ones could reduce the consumption of electricity. However, in developing countries that are on the starting phase of industrialization, their industrial growth could increase the consumption of electricity as this form the accumulation of new electricity consumption devices. Most of the literature used the Industrial Value Added as a proxy for industrialization[49–52]. Figure 10 describes the evolution of the variable Industry value added.

3.1.2.6. Consumer price index (CPI)

The Consumer Price Index (CPI) is strongly linked to the inflation rate. Thus, inflation is the annual rate of change of CPI. As highlighted by the literature, inflation positively affects electricity prices [4,16,34]. Therefore, most regulatory authorities in setting the base tariff, they take into account macroeconomic factors among which national inflation[33,34,53]. However, as inflation rate is the annual rate of change of CPI, the variable inflation is considered as the first difference of CPI. This implies that the variable inflation is stationary at level or integrated with order zero I(0) as indicated in Table 3. For co-integration tests between variables, they should be non-stationary at level and integrated with the same order. Therefore, we consider CPI which is non stationary at level and integrated with order one as other variables instead of Inflation. Figure 11 describes the evolution of the variable Consumer Price Index.

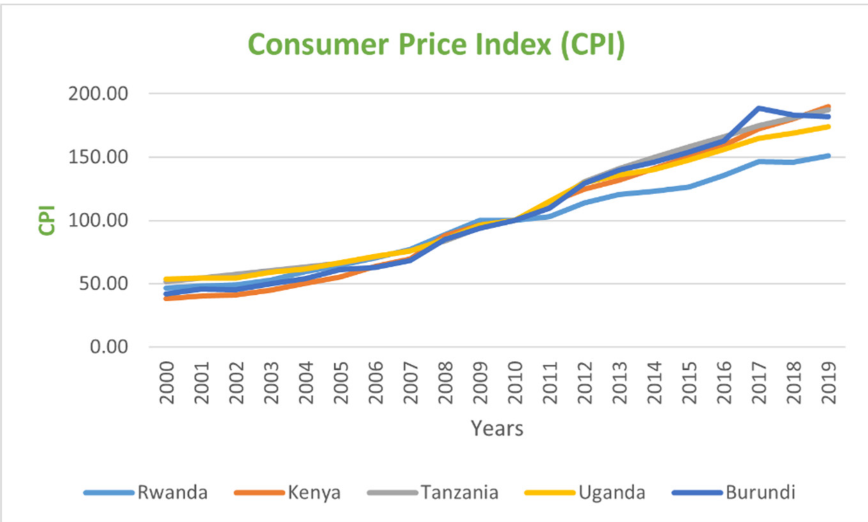

Figure 11. Evolution of consumer price index.

3.2. Panel data and econometric model

Table 2. Econometric model abbreviations.

Nº	Abbreviation	Explanation
1.	ADF	Augmented dicky fuller
2.	BLUE	Best linear unbiased estimator
3.	DOLS	Dynamic ordinary least squares
4.	FEM	Fixed effect model
5.	FMOLS	Fully modified ordinary least squares
6.	GLS	Generalized least squares
7.	i.i.d.	Independent and identically distributed
8.	IPS	Im, Pesaran, and Shin
9.	LLC	Levin, Lin & Chu
10.	OLS	Ordinary least squares

The use of panel cointegration techniques to test for the presence of long-run relationships among integrated variables has been appreciated by an increasing number of researchers [54]. The use of panel data which comprises data observed for N entities (countries, regions, cities, firms, and so on) over T periods gives the researcher a large number of observations, increasing the number of degrees of freedom and reducing the collinearity among explanatory variables. Besides that, it is well known that panel data models are better able to deal, in a more natural way with the effects of missing or unobserved variables [55]. The literature describes different characteristics of panel datasets and models. Hill et al. [56] clearly note that the panel data set can be balanced or unbalanced. As missing data are very common in panel data sets, panels in which group sizes differ across groups are called "unbalanced" while when T periods data are all available for all N entities, the panel data sets are called "balanced panels" [57].

Most of the literature agrees on three-panel data regression models that are mostly used in the econometric analysis [56–61]. The first consist of Pooled Model, the second is the Fixed Effect Model as well as the Random Effect Model. In Pooled Model, the data on different individuals are simply pooled together with no provision for individual differences that might lead to different coefficients. However, this model presents some drawbacks related to the fact that it does not include unobserved heterogeneity. This implies that this model does not take into account the specificities of the various countries of the sample. A pooled model with two explanatory variables can be written as:

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \mu_{it} \tag{1}$$

where "i" denotes the *i*th country and "t" denotes the *t*th period. Thus, "Y_{it}" represents the *t*th observation on the dependent variable for the *i*th country, while "X_{it}" represents the *t*th observation on the independent variable for the *i*th country.

The coefficients in Eq (1) are assumed to be constant for all "*i*" countries in all time periods, and do not allow for possible individual heterogeneity. It is this characteristic that leads it to be called a pooled model. An alternative way to use panel data is to view the unobserved factors affecting the dependent variable as consisting of two types: those that are constant and those that vary over time. Letting *i* denote the cross-sectional unit and *"t"* the time period, we can write a model as:

$$Y_{it} = \beta_{1i}X_{1it} + \beta_{2i}X_{2it} + \cdots + \beta_{ki}X_{kit} + \alpha_i + \mu_{it} \quad (2)$$

The variable a_i captures all unobserved time-constant factors that affect y_{it}. Generically, a_i is called an unobserved effect. It is also common in applied work to find a_i referred to as a fixed effect, which helps us to remember that a_i is fixed over time [58].

It is generally admitted that it is necessary to introduce a minimum of heterogeneity into the model to take account of the specificities of the various countries of the sample. The simplest method for introducing parameter heterogeneity consists of assuming that the constants of the model vary from country to country. This is precisely the specification of the well-known individual or fixed effect model (FEM). Ignoring such parameter heterogeneity could lead to inconsistent or meaningless estimates of interesting parameters. The individual effects can be fixed or random. When individual effects are assumed to be fixed, the simple Ordinary Least Squares (OLS) estimator is the BLUE (Best Linear Unbiased Estimator) and is commonly called a *Within* estimator. When individual effects are specified as random variables, they are assumed to be independent and identically distributed (*i.i.d.)*. In this case, the BLUE is a Generalized Least Squares (GLS) estimator [62].

However, various scholars like Chen et al. [63] studied the proprieties of the OLS estimator and suggest that alternatives estimators, such as the Fully Modified Ordinary Least Squares (FMOLS) or the Dynamic Ordinary Least Squares (DOLS) estimators, maybe more promising in cointegrated panel regressions. In addition, Daniel [54] cites Ouedraogo [64] in his article to point out that in the cointegrated panels, using the ordinary least squares (OLS) method to estimate the long-run equation leads to a biased estimator of the parameters unless the regressors are strictly exogenous and conclude that the OLS estimators cannot generally be used for valid inference. Therefore, this study uses FMOLS and DOLS to estimate the coefficients of the long-run relationship between EP, EG, Losses, EC, FP, CPI, and IVA for Rwanda, Tanzania, Uganda, Burundi, and Kenya. The FMOLS and DOLS estimators are generated from the following equation:

$$Y_{it} = \alpha_i + X'_{it}\beta + \sum_{j=-q_1}^{j=q_2} c_{ij}\Delta X_{i,t+j} + \mu_{it} \quad (3)$$

where:
Y_{it}: represents the log of the dependent variable,
X: is the log of explanatory variables,
β: denotes the coefficients of explanatory variables,
c_{ij}: represents the coefficients of lag differenced variables,
α_i: Individual Effects and μ_{it} denotes the error term.

The variables used in panel data analysis should be stationary to avoid causing possible spurious relationships among the variables. To assess the stationarity properties of the variables used, this study utilizes four different panel unit root tests including ADF-Fisher Chi-square, PP-Fisher Chi-square, Levin, Lin, and Chu, hereafter referred to as LLC [65]; Im, Pesaran, and Shin, hereafter referred to as IPS [62], this test is less restrictive and more powerful compared to others like LLC which do not allow for heterogeneity in the autoregressive coefficient. The test proposed by IPS solves Levin and Lin's serial correlation problem by assuming heterogeneity between units in a dynamic panel framework [66]. The basic equation for the panel unit root test for IPS is as follows:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{p} \Phi_{ij}\Delta y_{i,t-j} + \varepsilon_{i,t}; \quad i = 1,2,\dots,N; \quad t = 1,2,\dots,T, \quad (4)$$

where y_{it} stands for each variable under consideration in our model, α_i is the individual fixed effect, $\varepsilon_{i,t}$ is the error term, ϕ_{ij} represents the coefficients of lag differenced of variables and ρ_i is selected to make the residuals uncorrelated over time.

Once the variables considered are stationary and before the estimation of the unbiased coefficients, we use Kao and Johansen Fisher co-integration tests to determine whether there is a long-run relationship between EP, EG, Losses, EC, FP, CPI, and IVA. In addition, this study will also apply cointegration tests advanced by Pedroni [67], despite that these tests have been criticized for the common factor restriction condition to hold and their failure can cause a significant loss of power for residual-based cointegration tests.

The functional econometric log-log model is used. The main advantage of using the log-log model, is that the estimated coefficients are expressed as elasticities. The econometric model describes the relationship between Average end-user Electricity Prices (EP), Electricity Net Generation (EG), Electricity Transmission and Distribution losses (Losses), Electricity Net Consumption (EC), International Average Crude oil prices (FP), Consumer Price Index (CPI) and Industry value added (IVA) for Rwanda, Tanzania, Uganda, Burundi, and Kenya is as follows:

$$logEP_{it} = \beta_0 + \beta_1 logEG_{it} + \beta_2 logLosses_{it} + \beta_3 logEC_{it} + \beta_4 logFP_{it} + \beta_5 logCPI_{it} + \beta_6 logIVA_{it} + \alpha_i + \mu_{it} \quad (5)$$

where:

Log (EP_{it}) = The natural logarithm of the Average Electricity Prices of the country "i" at the time "t" in US$/kWh
Log (EG_{it}) = The natural logarithm of the Electricity Net Generation of the country "i" at the time "t" in kWh
Log ($Losses_{it}$) = The natural logarithm of Total System Losses (Transmission and Distribution) of the country "i" at the time "t" in kWh.
Log (EC_{it}) = The natural logarithm of the Electricity Net Consumption of the country "i" at the time "t" in kWh
Log (FP_{it}) = The natural logarithm of International Average Crude oil prices in the country "i" at the time "t" in US$/gallon (This price is the same for all countries)
Log (CPI_{it}) = The natural logarithm of the Consumer Price Index of the country "i" at time "t"
Log (IVA_{it}) = The natural logarithm of the industry value added of the country "i" at the time "t" in US$
α_i = Individual Effects
μ_{it} = Error Term
β = Coefficients to be estimate

4. Results and discussions

This paper adopts a three-stage approach as follows:

i. panel unit root tests,
ii. panel cointegration tests,
iii. panel coefficients estimation to study and evaluate to which extent EG, Losses, EC, FP, CPI, and

IVA affect the electricity prices (EP) for Rwanda, Tanzania, Uganda, Burundi, and Kenya.

4.1. Panel unit root test results

The unit root tests have been carried out to establish whether the variables are stationary or non-stationary at "level" and in "first-differences". Unit root tests are tests for stationarity in a time series. A time series has stationarity if a shift in time doesn't cause a change in the shape of the distribution; unit roots are one cause for non-stationarity. Four different tests have been used, these include the Levin, Lin & Chu (LLC), the Im, Pesaran, and Shin (IPS), the ADF-Fisher Chi-square, and the PP-Fisher Chi-square. The unit root statistics are reported in Tables 3 and 4.

The statistics in Table 3 presents the results from unit root test at level. In statistics, a unit root test tests whether a time series variable is non-stationary and possesses a unit root. The null hypothesis is defined as the presence of a unit root or non-stationary and the alternative hypothesis is either stationarity or trend stationarity. If the probability is greater than 5% or 0.05, the null hypothesis cannot be rejected and implies that the variable is non-stationary. Based on the results in Table 3, all probabilities are greater than 5% or 0.05, and we can conclude that the null hypothesis of the presence of a unit root cannot be rejected for all tests. This implies that they are non-stationary at level.

Table 3. Panel unit root tests results of the variables at level.

Null Hypothesis: Has Unit Root →non-Stationary Alternate Hypothesis: Does not have Unit Root →Stationary									
Methods		Levin, Lin & Chu (LLC)		Im, Pesaran and Shin (IPS) W-stat		ADF-Fisher Chi-square		PP-Fisher Chi-square	
		Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend
Variables									
Level	Log (EP)	–1.14477	2.08900	–0.19504	2.53937	11.1786	2.84759	7.02668	1.14364
	Prob	(0.1262)	(0.9816)	(0.4227)	(0.9944)	(0.3438)	(0.9848)	(0.7229)	(0.9997)
	Log (EG)	0.72249	–1.96002	3.79067	0.14513	1.07888	9.00057	7.50197	37.2936
	Prob	(0.7650)	(0.0250)	(0.9999)	(0.5577)	(0.9998)	(0.5320)	(0.6774)	(0.0001)
	Log (Losses)	2.86129	0.96983	3.27317	0.99494	3.77754	7.01685	7.43760	11.4109
	Prob	(0.9979)	(0.1661)	(0.9995)	(0.8401)	(0.9568)	(0.7239)	(0.6836)	(0.3264)
	Log (EC)	1.47598	–0.90628	3.89270	–0.85769	1.18627	13.6224	5.38390	28.7571
	Prob	(0.9300)	(0.1824)	(1.0000)	(0.1955)	(0.9996)	(0.1909)	(0.8641)	(0.0014)
	Log (FP)	–2.52756	0.07141	–1.64365	1.03623	15.9106	3.64899	8.7373	1.63924
	Prob	(0.0057)	(0.5285)	(0.0501)	(0.8500)	(0.1022)	(0.9618)	(0.5572)	(0.9984)
	Log (CPI)	–2.86046	–2.54488	–2.74800	–1.19721	25.6143	16.7217	31.0123	25.0948
	Prob	(0.0921)	(0.0855)	(0.2930)	(0.1156)	(0.0843)	(0.0808)	(0.4566)	(0.3452)
	Log (IVA)	–1.62393	–0.43331	1.29044	21.290	4.06528	6.91779	4.84217	4.31595
	Prob	(0.0522)	(0.3324)	(0.9016)	(0.5843)	(0.9444)	(0.7332)	(0.9015)	(0.9320)

The results in Table 4 show that after taking the first difference of the variables, LLC, IPS, ADF-Fisher Chi-square, and PP-Fisher Chi-square panel unit root tests reject the null hypothesis at a 1% significance level for EG, EC, FP, CPI, Losses, and IVA variables. Concerning EP, the statistics reject the null hypothesis with constant and trend at less than 1% with PP-Fisher Chi-square test, at less than 5% with IPS and the ADF - Fisher Chi-square panel unit root tests, and at 6% with LLC test. Therefore, we can conclude that all variables are stationary and integrated with order one, I (1). As all variables are stationary at first difference and integrated with the same order which is one, implies that we can proceed with co-integration tests to determine whether there is a long-run relationship or equilibrium among the variables under variables.

Table 4. Panel unit root tests results of the variables at first difference.

Null Hypothesis: Has Unit Root →non-Stationary Alternate Hypothesis: Does not have Unit Root →Stationary									
Methods		Levin, Lin & Chu (LLC)		Im, Pesaran and Shin (IPS) W-stat		ADF-Fisher Chi-quare		PP-Fisher Chi-square	
		Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend
Variables									
First difference	ΔLog (EP)	–1.12435	–1.52796	–1.41846	–1.98680	16.0131	20.1155	40.2887	56.4666
	Prob	(0.1304)	(0.0633)	(0.0780)	(0.0235)	(0.0993)	(0.0282)	(0.0000)	(0.0000)
	ΔLog (EG)	–5.76548	–6.44348	–5.66003	–5.71215	48.4942	46.1986	90.9441	110.107
	Prob	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	ΔLog (Losses)	–4.57520	–5.30875	–5.01663	–5.60254	43.2696	45.3499	113.617	88.8381
	Prob	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	ΔLog (EC)	–5.64146	–6.52383	–6.50226	–6.34644	56.0913	51.0100	343.615	79.7705
	Prob	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	ΔLog (FP)	–4.46724	–4.69960	–2.77599	–2.31841	24.1772	20.8984	40.6758	35.1141
	Prob	(0.0000)	(0.0000)	(0.0028)	(0.0102)	(0.0071)	(0.0218)	(0.0000)	(0.0001)
	ΔLog (CPI)	–3.54003	–4.47617	–3.03765	–2.42538	27.0679	23.6062	30.4908	24.8252
	Prob	(0.0002)	(0.0000)	(0.0012)	(0.0076)	(0.0025)	(0.0087)	(0.0007)	(0.0057)
	Prob	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	ΔLog (IVA)	–3.74434	–3.14605	–2.98534	–1.80649	26.3404	18.4526	38.6912	28.2769
	Prob	(0.0001)	(0.0008)	(0.0014)	(0.0354)	(0.0033)	(0.0478)	(0.0000)	(0.0016)

4.2. Panel cointegration test results

Having established that all variables are integrated with the same order, we apply Pedroni, Kao and Johansen Fisher co-integration tests to determine whether there is a long-run relationship or equilibrium among the variables: EP, EG, Losses, EC, FP, CPI, and IVA. If the variables are cointegrated, implies that the equation 5 can be estimated and provide unbiased coefficients. Pedroni [67] suggested some tests which allow heterogeneity in the co-integration analysis. This test does not allow only dynamic and fixed effects to be different among the cross sections of the panel, but also allows the co-integrated vector to be different among the cross sections under the alternative hypothesis allowing multiple regressors, varying of co-integration vector in different parts of the panel and allowing heterogeneity of errors through cross-sectional units constitute good sides of Pedroni's tests [30]. Pedroni tests use four within-group tests which are panel statistics based on estimators that pool the autoregressive coefficient across different countries for the unit root tests on the estimated residual and three between-group tests that are group statistics based on estimators that average individually estimated coefficients for each country.

Table 5. Pedroni panel cointegration test.

Pedroni residual cointegration test					
Methods	Within dimension (Panel statistics)			Between dimension (Individuals statistics)	
	Test	Statistics	Prob.	Statistics	Prob.
Pedroni	Panel v-statistic	0.472062	0.3184	-	-
	Panel rho-statistic	1.404765	0.9200	1.747855	0.9598
	Panel PP-statistic	–3.024805	0.0012	–4.411635	0.0000
	Panel ADF-statistic	–3.840508	0.0001	–5.051929	0.0000
Pedroni (Weighted statistic)	Panel v-statistic	0.750266	0.2265	-	-
	Panel rho-statistic	1.111894	0.8669	-	-
	Panel PP-statistic	–3.593525	0.0002	-	-
	Panel ADF-statistic	–4.578828	0.0000	-	-

Table 5 reports the within and between dimension results of the panel cointegration tests. These results suggest that the null hypothesis of no cointegration cannot be rejected for five tests out of eleven. However, six tests out of eleven suggest that the null hypothesis of no cointegration can be rejected at a 1% significance level. This implies that, as more than half of the tests propose the rejection of the null hypothesis, we may conclude that the variables of the model are cointegrated and therefore exhibit long-run relationship. To check the robustness of the Pedroni's test results, the Kao and Johansen Fisher co-integration tests are performed to confirm these first results. Table 6 provides the results of the Kao residual panel cointegration test, which reject the null of no cointegration of the variables of the model at the 1% level of significance. In addition, the Johansen Fisher Panel Cointegration Test results reported in Table 7, provide also strong evidence of the cointegration relationship between all variables, indicating that there are at most 3 cointegrating equations. Based on the above results, we can conclude that all variables are cointegrated and have a long-run equilibrium relationship between EP, EG, Losses, EC, FP, CPI, and IVA in East African countries.

Table 6. Kao residual cointegration test.

Kao residual cointegration test Null hypothesis: No cointegration		
ADF	t-Statistic	Prob.
	–3.369657	0.0004
Residual variance	0.004641	
HAC variance	0.003789	

Table 7. Johansen fisher panel cointegration test.

Unrestricted cointegration rank test (Trace and maximum eigenvalue)				
Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	124.4	0.0000	129.5	0.0000
At most 1	47.66	0.0000	28.97	0.0013
At most 2	24.17	0.0072	13.20	0.2126
At most 3	14.61	0.1470	8.555	0.5748
At most 4	10.63	0.3870	5.269	0.8725
At most 5	11.87	0.2941	11.21	0,3410
At most 6	11.52	0.3182	11.52	0.3138

*Probabilities are computed using asymptotic Chi-square distribution.

4.3. Coefficients estimation results with FMOLS and DOLS

As highlighted in the literature, this study uses two techniques to estimate and test the consistency of the unbiased coefficients of the long-run relationship between the variables. This relationship has been estimated by using the FMOLS and the DOLS methods. FMOLS method corrects the biases of estimators with standard fixed effects which could arise from problems such as autocorrelation and heteroscedasticity, while the DOLS method can correct biases of static regression which could result from endogeneity problems by including dynamic considerations in the model [30]. Tables 8 and 9 show the results and given that the variables are expressed in a natural logarithm, the coefficients can be expressed and interpreted as elasticities.

The overall outcomes of this study show that there is a strong long-run relationship between the dependent and independent variables. The independent variables explain the variations in electricity prices at 91% for both DOLS and FMOLS as shown by the R-squared. It is interesting to note that the regression results for both methods are quite similar in negative or positive signs, magnitude, and significance level of coefficients. The panel regression results indicate that the overall considered variables are statistically significant at a 1% level, except EC which is statistically significant at 2% for DOLS only.

The variable Electricity Generation (EG) has a positive estimated coefficient, showing that a 1% increase in EG, causes an increase of 0.5% in the electricity prices (EP). This is in line with the findings of Shields and Chris Sayers [1] in their research related the electricity prices and cost factors. They point out that the lack of economies of scale in electricity generation could cause the increase in electricity prices as the electricity generation increases. This could be attributed to lesser leakages and power losses obtained in larger generating units as well as operating and maintenance costs that increase less than proportionally with power plant unit size. Due to the insufficiency of financial and human resource means, most developing countries develop electricity generating units that are not large enough to benefit from the economies of scale of generating units. This could affect the electricity cost of production and price. Even if most of the literature agrees that the increase of renewable sources in electricity generation reduces the electricity prices [10,12,17,36], the results of this study show that the increase in renewables for Kenya and Burundi have not reduced the electricity prices. This can be explained by the fact that hydropower generation requires huge investments and the private investors in the sector for developing countries require short payback period. Therefore, this can increase the prices in short term and expect to reduce prices in long term.

Moreover, the positive relationship between electricity generation and electricity prices in countries under study, can be attributed to the structure of the electricity generation mix in the East African countries in the research sample. Most of the countries are still more dependent on fossil fuels for electricity generation. It is significant to note that for example in 2020, fossil fuels in electricity generation mix were 33% in Burundi, 39% in Rwanda, and 65% in Tanzania and this was the same pattern in the previous years. As this source of electricity is one of the most expensive, this could explain why the cost of electricity production increases results in the average electricity price also increasing. This in some respects corroborates the results of the positive sign on the Fuel Price (FP) variable, which shows that a 1% increase in FP, also causes a 0.2% increase in the electricity price, this is in line with the findings of various scholars [7,10,12] . Moreover, in the framework of increasing their electricity generation capacity, East African Countries in general, have started to invite foreign investors with the required human and financial resources means. Projected returns would have to be attractive enough to encourage investment, therefore, country utility regulators should have to set electricity prices that cover all costs related to electricity generation, transmission and distribution as well as earn a positive return on their investments. This could also explain why the increase in electricity generation results in an increase the electricity prices.

Table 8. Panel FMOLS long-run estimation results.

Dependent variable: LEP
Method: Panel fully modified least squares (FMOLS)
Sample (adjusted): 2001 2019
Periods included: 19
Cross-sections included: 5
Total panel (balanced) observations: 95

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LEG	0.505354	0.070970	7.120692	0.0000
LLOSSES	–0.222519	0.036648	–6.071736	0.0000
LEC	–0.239851	0.072683	–3.299935	0.0014
LFP	0.248166	0.021433	11.57863	0.0000
LCPI	0.238064	0.028054	8.485913	0.0000
LIVA	–0.299632	0.044162	–6.784775	0.0000
R-squared	0.913429			
S.E. of regression	0.079267			

Concerning the Electricity Transmission and Distribution losses (Losses), the regression outcomes show that the increase in 1% of losses, decreases the average electricity price by 0.2%, while for Electricity Consumption (EC) an increase of 1% reduces the average electricity prices of 0.2%. This result supports the findings of various scholars who found a close relationship between electricity consumption or demand with electricity prices [5,12,18]. However, developing countries tend to use oil fired electricity generation in hours or days of peak demand, and this require higher cost of production than renewables. Thus, the increase in electricity demand or consumption could increase the electricity prices. One of the economic characteristics of the electricity supply is its capital intensiveness. Therefore, the investments if not well-planned can result in stranded assets and with a very high proportion of fixed assets. Due to this reason, economies of density and output in distribution can affect electricity cost of production and prices. This implies that the average cost of servicing a particular area decline as the number of customers in that area using existing assets increases, or as the average load drawn by those customers increases [1].

Table 9. Panel DOLS long-run estimation results.

Dependent variable: LEP
Method: Panel dynamic least squares (DOLS)
Sample: 2001 2019
Periods included: 20
Cross-sections included: 5
Total panel (balanced) observations: 100

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LEG	0.525211	0.126392	4.155405	0.0001
LLOSSES	–0.241122	0.064613	–3.731795	0.0003
LEC	–0.264953	0.112249	–2.360409	0.0204
LFP	0.228005	0.034616	6.586598	0.0000
LCPI	0.227116	0.053747	4.225647	0.0001
LIVA	–0.225842	0.064731	–3.488947	0.0008
R-squared	0.912995			
S.E. of regression	0.079910			

Consumer Price Index (CPI) has a positive effect on electricity prices. More specifically, the increase of 1% in CPI, increases the average electricity prices increase by 0.2%. This result is in line with the findings of several studies whether in developed or developing countries. As highlighted in the literature, inflation or the increase in CPI positively affects electricity prices [4,16,34]. In addition, most regulatory authorities in setting the base tariff, they take into account macroeconomic factors among which national inflation or CPI [33,34,53]. Lastly, the variable Industry Value Added (IVA) has a negative effect on electricity prices such that increase of 1% in IVA, decreases electricity prices by 0.29%. Most of the literature used the Industrial Value Added as a proxy for industrialization [49–52] and have found a significant relationship between IVA and EP. In addition, for developed countries, Foroni et al. [18], to analyze the importance of macroeconomic information, for forecasting daily electricity prices in two of the main European markets, Germany and Italy. They also reach on the conclusion that industrial production index and oil price are more important for short horizons than for longer horizons pricing.

Moreover, the negative relationship between IVA and EP can be attributed to the efficient use of electricity by industries, which is one a key factor of production. This support the findings of Dan [47] who clearly noted that there has been a gradual decline in energy consumption in China since 1978 despite increasing industrial growth and attributed this to energy efficiency. The results of this study imply that an increase in industrialization through efficient use of electricity or any other factors such as energy efficiency practices that affect electricity consumption, can reduce average end-user electricity prices to the consumer. It is important to note that the behaviors of the drivers of EP could also change depending on the economic structure, energy policy of governments and price regulation policies of the countries.

5. Conclusion, regulatory implications, and policy recommendations

The objective of this study, is to measure to which extent, Electricity Net Consumption (EC), Electricity Net Generation (EG), electricity transmission and distribution losses (Losses), International Average Crude oil prices (FP), Consumer Price Index (CPI), Industry Value Added (IVA) could influence the Average Electricity Prices (EP) in five countries of East Africa for a period of 2000 to 2019. This study adopts a three-stage approach, consisting of panel unit root, panel cointegration tests and estimating the long run cointegration relationship of the variables in a panel context. We applied four different panel unit root tests including ADF-Fisher Chi-square, Levin, Lin and Chu (hereafter referred to as LLC); PP-Fisher Chi-square, and Im, Pesaran, and Shin, (hereafter referred to as IPS). The results of the tests reveal that the variables are non-stationary at "level", stationary at first-differences and integrated with order one denoted as I(1). For cointegration analysis, the Pedroni, Kao and Johansen Fisher co-integration tests were performed. The results of the tests reject the null hypothesis of no cointegration of the variables at 1% level of significance. Therefore, we can conclude that there is a long-run relationship between all variables.

FMOLS and DOLS coefficients estimation results, demonstrated that the independent variables explain the variations in electricity prices at 91% as shown by the R-squared. In addition, the overall considered variables are statistically significant at a 1% level, except EC which is statistically significant at 2% for DOLS only. The panel coefficients estimation indicates that 1% increase in EG, leads to 0.5% increase in the electricity prices (EP); 1% increase in FP, causes a 0.2% increase in the electricity price; 1% increase in losses, decreases the average electricity price by 0.2%; an increase of 1% in EC reduces the average electricity prices of 0.2%; an increase of 1% in CPI, increases the average electricity prices increase by 0.2%, and an increase of 1% in IVA, decreases electricity prices by 0.29%.

The results revealed the existence of a negative long run relationship from electricity generation and fuel prices to electricity prices. This study recommends that governments should develop policies to support development of renewable sources which are also environmentally friendly, to increase the share of renewables in the overall energy mix in East African countries. They should renegotiate some of the terms and conditions of the agreement with the investment firms that were entrusted with the generation of hydroelectricity especially in terms of payback periods. They could also utilize equity financing arrangements, which are cheaper to reduce the electricity cost of production. This could reduce in long term the electricity prices. In addition, appropriate policies related to subsidized electricity prices need to be reformulated, to prevent adverse effects related to inefficient over-consumption of electricity. Furthermore, despite that subsidized electricity prices offset the negative effects of losses on electricity prices, the regulatory policies should adopt a performance-based regulation to cope the utilities to reduce the technical and commercial losses which can increase end-user electricity prices.

This study is a first attempt to determine the drivers of electricity price in East African countries. The current study provides good insight into the behaviors of the key drivers of electricity prices in the East Africa region that could shape policy and regulatory decisions that will make the electricity sector financially viable and sustainable. Going forward, the authors have however identified some areas which can be improved upon in future studies. For instance, since investment affects electricity prices and is driven largely by peak capacity needs, it will be appropriate to have in the econometric model, Peak Demand (MW) as one of the independent variables. Also, for robust results in future studies, it will be important to disaggregate the total loss variable into Distribution System Losses (technical and commercial losses) and Transmission System Losses.

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Conflict of interest

The authors declare no conflicts of interest.

Authors' contributions

Mr. Mburamatare Daniel: Conception, design of the study, interpretation of data and drafting the article; Dr. Akumuntu Joseph: Acquisition of data, analysis and interpretation of data; Dr. William K. Gboney: Critically revising its important intellectual content; Dr. Hakizimana Jean de Dieu: Final approval of the version submitted; Dr. Fidele Mutemberezi: Support in the analysis and interpretation of data.

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