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Balancing short-term costs and long-term benefits: an analysis of the impact of hydroelectric power generation on electricity prices volatility in Cameroon

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Abstract

This study examines the short- and long-term impacts of various factors on the volatility and price of electricity in Cameroon, including hydroelectric power generation, economic growth, energy demand, and exchange rates from 2000 to 2019. The study uses an autoregressive distributed lag model. The study found that increasing hydroelectric power generation has both positive and negative impacts on electricity prices in the short and long term. While increasing the share of hydropower in overall energy production results in increased variation of electricity costs in the short term, it leads to significant price reductions in the long run. The study also found that economic growth has a considerable positive impact on the variation of power prices, while energy demand has a negative but insignificant effect on price volatility in the short term. Further, the study indicates that measures, such as encouraging SME engagement in renewable energy production, could improve the participation of local enterprises in the power industry and reduce the volatility of electricity prices. On the other hand, the study suggests that exchange rates could have a negative impact on electricity prices in the short term, but depreciation of the local currency could lower fuel costs and improve the availability of power. Overall, the study provides insights that can inform policymakers, energy regulators, and investors in making decisions that contribute to the efficient and sustainable development of Cameroon's electricity market. The study also highlights the need to prioritize power generation to stimulate economic growth and private investment while promoting renewable energy production.

Keywords Volatility, Electricity price, Hydroelectric power generation, Economic growth, Energy demand, Exchange rates

Introduction

Renewable energy sources are one of the key elements of climate change strategies and scenarios (Newbery et al., 2019). They are also recognized as a way to reduce energy dependency or promote new economic sectors and activities in some countries (Würzburg et al., 2013).

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Price volatility is a crucial indicator of price uncertainty. Newbery and Stiglitz (1984) show that even under the unlikely assumption that the producer is not risk-averse, price instability and thus income instability lead to lower average output when prices and quantities are negatively correlated.

According to the International Renewable Energy Agency (IRENA, 2020), global renewable energy power output increased by 56.74% between 2010 and 2018. It increased from 4202026 gigawatt-hour (GWh) in 2010 to 6586124 GWh in 2018. Sub-Saharan Africa has climbed from 96309.17 GWh (or 2.29% of global output) in 2010 to 134711.61 GWh (or 2.05% of global production) in 2018, with a population of 1074866715 people. This is less than Norway, which generated 142 937 GWh for a population of just 5 311 916 people. Furthermore, this electricity production is mostly produced by 12 countries (Mozambique, Zambia, Ethiopia, South Africa, the Democratic Republic of the Congo, Sudan, Kenya, Angola, Nigeria, Ghana, Zimbabwe, and Cameroon), with a contribution a production volume of 113836.53 GWh representing 87,44% of the whole sub-Saharan production. The remaining 12.56% of the electricity production is produced by the other 36 African countries.

In Cameroon, compared to the rest of Central African countries, electrification rates are fairly high. In fact, 54% of the population has access to electricity, despite modest use. In addition, despite the fact that the country produced 70 kb/d of oil in 2013, these recent years, the production is gradually declining (IEA, 2022). Furthermore, the power output deficit in Cameroon has been worsened by the absence of a comprehensive policy on renewable energy. However, Mboumboue and Njomo (2016) showed that if the renewable energy and fossil fuels are utilized effectively, they may complement each other. In this case, the policymakers should promote and reinforce the development of the renewable energy and encourage aggressive diversification into alternative renewable and sustainable energy sources. For example, in Cameroon, the government planed that in 2021 the renewable energy would provide around 54 percent of Cameroon's electrical capacity, essentially constant from the preceding 2 years (IEA, 2022). According to the data available on Cameroon's electricity production, the total installed power capacity in 2020 was estimated at 1529 MW. This capacity was allocated among different types of power plants, including hydroelectric (61.7%), thermal (24.1%), gas-fired (14.1%), and solar (0.1%) power plants (Admin, 2022).

In sub-Saharan Africa, hydropower is the most extensively utilized renewable energy source. It has a strong position in Cameroon's energy industry, accounting for 75 percent of power generation (Muh et al., 2018). With an installed capacity of 732.2 MW in 2018, it is rated 18th in the world and 3rd in Africa. However, only 3% of an estimated 23 GW potential is being used (Mas'ud et al., 2015; Tamba et al., 2017). Nonetheless, hydropower is widely recognized as the world's most mature, flexible, dependable, and cost-effective renewable energy technology. In the near run, the large initial capital expenditure involved with adopting hydropower technology might benefit generating costs and consequently end-user tariffs (Adom et al., 2018).

The literature on the nexus between electricity prices and renewable energy production is very rich and controversial. Some believe that increasing the supply of renewable energy lowers electricity prices (Adaduldah et al., 2014; Adom et al., 2018; Clò et al., 2015; Gelabert et al., 2011; Holttinen, 2004; Jensen & Skytte, 2002; Möbius & Müsgens, 2015; Mulder & Scholtens, 2016; Pažėraitė, 2016; Tveten et al., 2013; Wen et al., 2022; Wozabal et al., 2016). In turn, electricity price volatility is reduced through increased renewable energy generation. Others find that electricity prices increase when renewable energy production increases (Adom & Bekoe, 2013; Brancucci Martinez-Anido et al., 2016a, 2016b; Csereklyei et al., 2019; Green & Vasilakos, 2010; Ketterer, 2014; Klinge Jacobsen & Zvingilaite, 2010; Milstein & Tishler, 2011; Möbius & Müsgens, 2015; Nibedita & Irfan, 2022; Sáenz de Miera et al., 2008; Soneji et al., 2017; Stringer et al., 2024; Traber & Kemfert, 2009; Woo et al., 2011). Despite the ongoing discussion, little is known about the impact of renewable energy generation on electricity prices in developing countries, particularly Cameroon. This study attempts to fill this empirical gap. It examines the short- and long-term impacts of various factors on the volatility and price of electricity in Cameroon, including hydroelectric power generation, economic growth, energy demand, and exchange rates from 2000 to 2019.

This study enlightens and prolongs the existing literature on how the generation of renewable energy affects price fluctuations in the electricity market. Firstly, it enriches the literature by bolstering the merit order effect and justifying the necessity to develop and use the renewable energy. Secondly, our study emphasizes renewable energy by using the data stemming from the hydraulic energy source that is present in Cameroon. Indeed, while previous studies research (Adom et al., 2018; Frondel et al., 2022; Owolabi et al., 2022) have offered a theoretical rationale supporting the idea that an increase in the production of renewable electricity (specifically hydropower) can lead to a reduction in the variability of electricity prices, they have not directly tested this hypothesis. This paper distinguishes apart from their study because it demonstrates that the negative impacts of hydraulic energy on the volatility of electricity prices are just a short-term occurrence and not a long-term one. This result is significant since their study did not find this. Moreover, the results of this study offer suggestions for promoting sustainable energy growth and data that can be used to quantify, monitor, and, most importantly, manage the challenges associated with the energy transition in Central Africa region, in general, and Cameroon in particular. The dynamic model's econometric analysis is done a priori using a cointegration technique using the Auto Regressive Distributed Lags (ARDL) model established by Pesaran and Shin (1995).

The paper is organized as follows: "Review of the literature" section is a literature review. "Methodology and data" section provides the empirical data and formulates the empirical model. The empirical findings are presented and discussed in "Results" section. "Conclusion and policy implications" section includes a summary of the key results as well as policy recommendations.

Review of the literature

Although there is a consensus in the literature on the role of the moderating effect of renewable energy prices on the electricity market, i.e., the merit order effect, the conclusions on its influence on price variance are fairly different. As a consequence, the dampening impact of renewable energy on electricity cost levels has been thoroughly studied in several industries. Many studies, however, have been interested on the impact of renewable energy generation on the volatility of electricity prices, with mixed results concerning the direction of this effect. Several approaches have been developed to this end, including the assessment of the impact of wind, solar, and hydro on price level and volatility. For example, Ketterer (2014) used a generalized autoregressive conditional heteroscedasticity (GARCH) model to investigate the German market and finds that wind production increases price variance while load lowers it. Following an investigation of the Italian day-ahead wholesale energy market by Clò et al. (2015), the authors found empirical evidence of the merit-order effect. In their study, they showed that, since 2005, each increase of one GWh in the hourly average of daily output from solar and wind sources has, on average, decreased wholesale electricity prices by 2.3 euros per megawatt-hour (MWh) and has magnified the volatility of those prices. This trend was seen from 2005 to 2013. The impact on pricing has diminished over time, which is a direct consequence of the growing share of energy generated by wind and solar power.

Woo et al., (2011) used a linear regression model to examine historical spot prices in Texas. They find that increasing wind production causes price variation in this geographic region. Klinge Jacobsen and Zvingilaite (2010) demonstrated a bigger price fluctuation owing to increasing renewable energy in their research of the Danish market. They do, however, suggest that increasing renewable power decreases the frequency of peak pricing. (Milstein & Tishler, 2011) developed a two-stage game for power producers and discovered that intermittent renewable production increases price volatility.

Adom et al. (2017) discover in their analysis for Ghana that increasing the amount of renewable energy increases the variation of power prices in both the short and long term. Green and Vasilakos (2010) simulate the United Kingdom (UK) market in 2020, estimating monthly price distributions in a numerical supply function equilibrium model that includes elements such as wind output fluctuation, demand, and market competitiveness. According to their study, they noticed that there will be more price volatility in the UK power market in the future.

Brancucci Martinez-Anido et al., (2016a, 2016b) modeled the New England electricity system and found that electricity price volatility increases with wind penetration. Moreover, they identified a stronger effect of wind generation on short-term volatility than on longer-term volatility. Macedo et al. (2022) analyzed too the impact of wind power, and electricity inflow and outflow, on both the mean and volatility of the day-ahead electricity price in the SE3 BZ. They used a Seasonal Autoregressive Regression (SARMAX)/GARCH approach. Pereira et al. (2019) found that the merit-order effect of wind power is significant and that the influence of wind power is rather constant throughout the day. Additionally, it would seem that the flow of power electricity, whether it be import or export, causes a rise in the price of day-ahead electricity.

Maniatis and Milonas (2022) examined the effect of wind and solar power generation on wholesale electricity prices in the Greek electricity market between August 2012 and December 2018. The empirical results confirmed the existence of a merit-order effect, which was stronger in the case of wind power. Wen et al. (2022) examined the wind–hydro nexus via the merit-order effect of wind penetration on nodal prices in the New Zealand Electricity Market. The authors utilized a spatial econometric model to estimate the impact of wind generation on nodal prices in the Greek electricity market. They also predicted the level and variance changes in prices that would result from a 10% increase in wind penetration. Owolabi et al. (2022) examined the impact of hydropower on system electricity prices and price volatility in New England. They performed a robust holistic analysis of the average quantile effects, as well as the marginal contributing effects of hydropower. Those authors found that hydropower contributes to a reduction in system electricity prices and volatility.

Most of the literature mentioned above concluded that increased renewable electricity generation leads to increased price volatility. However, other studies do not generally support this hypothesis. For example, Wozabal et al. (2016) showed that increasing renewable energy shares can increase or decrease the variance of electricity prices. Their argument is supported by the analysis of the Austrian–German market area for the years 2007–2013. Furthermore, Jónsson et al (2010) showed in their study for Denmark that an increase share of expected wind generation in total load even decreases the variance of intraday prices. They found that the probability of extremely high prices is reduced for high wind shares, resulting in reduced price volatility.

Tveten et al., (2013), for example, evaluated historical data and found that photovoltaic (PV) production in Germany decreases price variance between 2009 and 2011. One probable reason for this tendency is that high PV output times generally coincide with low power costs. During these periods, peak prices occur less frequently due to the presence of PV plants and other renewable technologies with low short-term marginal costs. These technologies tend to replace conventional facilities like natural gas plants in the merit order, thus reducing the need for them to be utilized during peak demand times. According to Möbius and Müsgens (2015), increasing the amount of renewable energy may both raise and reduce price variance. They investigated the impact of increasing wind share on price variance using an investment and dispatch model rather than an empirical model. Those authors showed that in a stylized power system with three-generation technologies, increasing wind power decreases the variation of electricity prices when the percentage of wind production is low, but increasing wind power raises the variance of prices when the share is large. In this broad framework, they argued that conventional power plants' capping and ramping limits are the primary causes of this tendency. According to Rintamäki et al. (2017), wind power reduces daily price volatility in Denmark while increasing daily price volatility in Germany and weekly price volatility in both countries.

Csereklyei et al. (2019) discovered evidence for wind and solar merit-order effects, which means that increased wind and solar power resulted in reduced wholesale energy costs. Wholesale power costs would have been higher if these renewable sources had been used less.

Nibedita and Irfan (2022) conducted a study that analyzed the asymmetric effects of renewable energy generation on wholesale electricity prices within the Indian electricity market. They estimated asymmetries in wholesale electricity price reactions using a high-frequency (15-min time block) time series with 29,008 data using the Non-linear Autoregressive Distributed Lag (NARDL) modeling framework. Their study revealed that wholesale power price reactions to positive and negative shocks in solar/wind production are asymmetric.

Stringer et al. (2024) examine the effect of the electricity generation mix on the variation of electricity prices in Ontario's competitive electricity market from 2015 to 2022. Those authors used a series of regression specifications. They found that an increase in the mix of renewables and nuclear leads to a reduction in the price of electricity.

Most of the research conducted so far has focused on a specific nation or technology. One of the reasons why the analysis of price variance is more diverse than price level analysis is due to the existence of numerous definitions of price variation or variability. Different definitions of price volatility can be found in the literature. For instance, Wozabal et al. (2016) included the range of prices, frequency of price spikes, standard deviation of the logarithm of historical returns as computed from options, and variance of prices. The differences in the results obtained can be attributed to the selection of conceptual models, temporal perspective, and empirical estimates.

According to the above studies, there is still no consensus on the effects of renewables on electricity prices. This might be because previous attempts failed to account for renewables' dynamic influence on electricity prices. Because of the current electricity tariffs, the impact of renewables on electricity prices is expected to be positive in the near term. Significant reductions in electricity prices as a consequence of renewables, on the other hand, may balance the short-term expenses placed on customers, resulting in cheaper electricity prices in the long run. Thus, in theory, the modes described in the literature could resemble either the short or long run. We develop a dynamic electricity pricing model that incorporates the outcomes of the previous studies. We offer a dynamic electricity pricing model that takes into consideration the immediate and long-term impacts of hydroelectric production on price changes in Cameroon, based on the preceding studies.

Methodology and data

Theoretical foundation and model formulation

The relationship between electricity price volatility and renewable energy sources is of paramount interest due to its implications for economic development and environmental sustainability. Prior research on the impact of renewable energy shares in the energy mix on retail electricity prices has been unclear due to the significant influence of country-specific regulatory policy and market structure on retail electricity pricing (Trujillo-Baute et al., 2018). The theoretical basis for our empirical model is grounded in the notion that electricity price volatility is impacted by a combination of factors, including the composition of energy sources, economic demand, and dynamic exchange rate.

Drawing from economic theory, specifically the contestable markets framework as proposed by Baumol (1982), we posit that the share of hydro generation (HYDRO) serves as an indicator of the stability and predictability of electricity supply, and thus plays a crucial role in determining electricity price volatility. Moreover, the responsiveness of electric power demand (DE) to price fluctuations, particularly in the context of renewable energy sources, is central to understanding the dynamics of electricity pricing. Additionally, real gross domestic product (GDP) and the real effective exchange rate (REER) are integral to our theoretical framework as they capture the macroeconomic conditions influencing electricity price volatility.

Following this theoretical underpinning, our empirical model is formulated as:

$$EPv = f(HYDRO, DE, GDP, REER, DU), \quad (1)$$

where electricity price (EPv) is measured as the average end-user tariff in Cameroon CFA franc (XAF) per kilowatt hour. The electricity price volatility is calculated as the standard deviation using the expression in the equation, as illustrated by Adom et al. (2017):

$$EPv_t = \sqrt{\frac{1}{n}\sum\left(EP_n - \overline{EP}\right)^2}. \quad (2)$$

GDP was selected based on the notion that as income rises, economies will have more financial resources to invest in renewable energy sources. This is referred to as the income hypothesis. GDP also measures the size of a country's economy. The variables DE and REER were chosen based on research by Adom et al. (2017) to evaluate how households react to price volatility. The variable HYDRO represents large hydro and was chosen as a proxy based on the study by Frondel et al. (2022). In our model, the variable DU serves as a dummy variable, accounting for any unobserved influences or structural changes that are not directly captured by the main explanatory variables. Its inclusion is essential to capture the potential impact of this structural change on the relationship between EPv and the explanatory variables. The measurement and use of the dummy variable are essential to ensure the robustness of our model, in particular, to address potential endogeneity issues and maintain the integrity of our empirical results.

By drawing upon a comprehensive and diverse body of literature, Eq. (1) has been transformed into a logarithmic form to derive the direct elasticity, based on several influential works (Adom et al., 2017; Green & Vasilakos, 2010; Jónsson et al., 2010; Ketterer, 2014; Milstein & Tishler, 2011; Tveten et al., 2013; Woo et al., 2011). The transformed equation can be expressed as:

$$lnEPv_t = \beta_0 + \beta_1 lnHYDRO_t + \beta_2 lnDE + \beta_3 lnGDP_t + \beta_4 lnREER_t + \beta_5 DU + \varepsilon_t. \quad (3)$$

In this specification, each coefficient (β) represents the estimated impact of its corresponding variable on electricity price volatility, consistent with our theoretical expectations.[1] EPv is electricity price volatility; HYDRO is the share of hydro generation; DE is energy demand; GDPt is real gross domestic product; REER is the real effective exchange rate. Critically, the inclusion of the dummy variable is important to capture any residual or unobserved factors that could impact electricity price volatility, ensuring that the model takes into account potential unexplained variations.

Econometric method

Descriptive statistical analyses, which are often performed on raw data, offer an accurate representation of the understudied data and variable distribution. The time series plot, on the other hand, displays a graphical representation of the raw data (Fig. 1).

Checking for stationarity is an important notion in time series analysis. The statistical characteristics of a time series are said to be stationary if they do not vary over time. A stationarity test can help to determine the sequence of integration and the best strategy to utilize. The augmented Dickey–Fuller (ADF), developed by Dickey and Fuller (1979) and Perron (1990) is universal approaches for examining variable stationarity. The existence of a unit root is often defined as the null hypothesis, whereas stationarity is the alternative hypothesis. The Zivot and Andrews (ZA) unit root test (Zivot & Andrews, 1992) was used to account for a structural break. We also apply the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) (Kwiatkowski et al., 1992) unit root tests to the ZA tests to obtain more reliable results.

The Pesaran, Shin and Smith (PSS) bound test were used to determine the presence of a long-run relationship (Pesaran et al., 2001). The null hypothesis of no cointegration among variables is rejected if the estimated value of the F test is greater than the upper critical bound value when analyzing the long-run connection between study factors. The outcome is uncertain if the projected value of the F test falls between the lower and upper critical boundaries. The null hypothesis of no cointegration between variables is accepted if the calculated result of the F test is smaller than the lower critical constraint. Furthermore, if cointegration exists, both the short-run (ARDL) and long-run (ECM) will be stated. If no cointegration exists, just the short-run model (ARDL) is stated.

To analyze the econometric model, we adopted the cointegration approach by the ARDL method. The ARDL method allows us to conduct cointegration tests. The selection of this approach is supported by the following benefits: in the next step, we use the autoregressive distributed lag model (hereafter ARDL) to explore the

[1] A priori, we expect HYDRO to have a negative impact on EPv ($\beta_1 < 0$), DE to have a negative impact on EPv ($\beta_2 < 0$), GDP to have a positive impact on EPv ($\beta_3 > 0$) and REER to have a positive impact on EPv ($\beta_4 < 0$) .

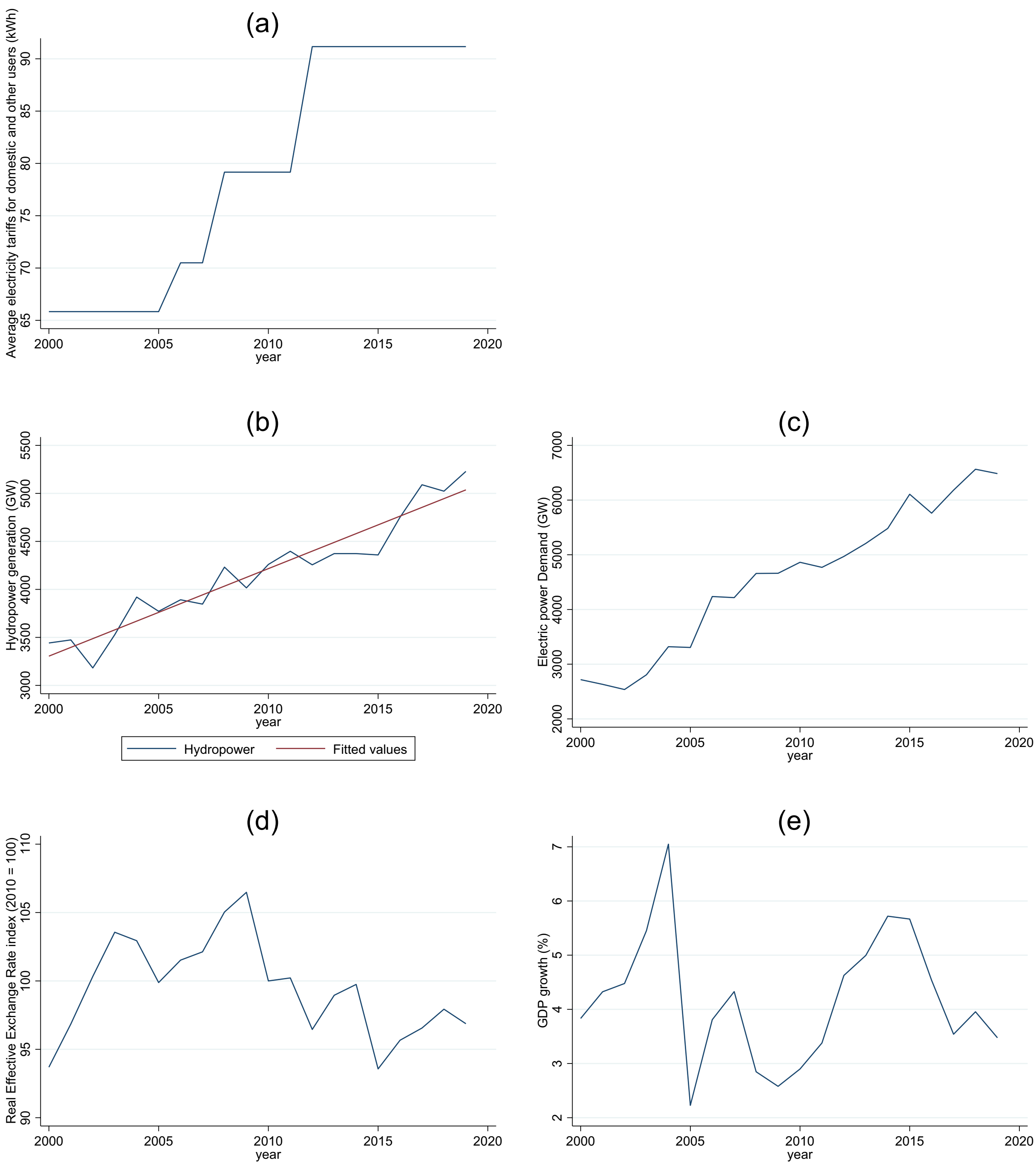

Fig. 1 Multi-variable time series analysis of electricity prices, hydroelectric power generation, electricity demand, real effective exchange rate, and growth rate in Cameroon (2000–2019). **a** Corresponds to the plot of the electricity price time series; **b** shows the hydroelectric power generation time series; **c** displays the electricity demand time series; **d** exhibits the real effective exchange rate time series; **e** illustrates the growth rate time series

relationship between renewable energy production and electricity prices (Adom et al., 2017), applying the cointegration procedure developed by Pesaran et al. (2001).

The ARDL approach is used when all variables are a mixture of I(0) and I(1). The ARDL model has several advantages over the standard multivariate cointegration test. First, it is a linked test procedure, and it is simple

Table 1 Descriptive statistics

Variables	Obs	Mean	Std. Dev	Min	Max	Skew	Kurt
ln EPv	20	0.387	2.235	−3.951	2.585	−1.342	3.074
ln_HYDRO	20	4170.85	564.388	3182	5229	0.215	2.352
ln_DE	20	4574.3	1325.502	2537	6564	−0.149	1.834
ln_GDP	20	4.186	1.196	2.228	7.049	0.492	2.941
ln_REER	20	99.42	3.543	93.568	106.482	0.179	2.351

Source: Authors

to follow. Second, this test can be applied regardless of whether the variables in the model are purely I(0), purely I(1), or whether it considers a mixture of variables of integration properties. Thus, this method eliminates the pre-testing problems associated with the standard cointegration test, such as the classification of variables as I(0) or I(1). Lastly, the use of the ARDL model in this study is required due to the unavailability of an extended time series dataset for electricity prices in Cameroon. The energy market in the country has undergone significant structural shifts, and acquiring reliable and consistent data over 30 years has proven to be challenging. Therefore, we made the deliberate choice to utilize the available 20-year dataset for our analysis to cover the most extensive period possible given the constraints associated with data availability. Additionally, the ARDL approach is especially well-suited for modeling dynamics in relatively short time series datasets as it enables the investigation of both short-term and long-term relationships among the variables of interest. Despite the relatively shorter timeframe, the ARDL methodology has been widely used and recognized for its robustness in capturing dynamic relationships in economic and energy-related analyses. Several recent studies employing the ARDL model with data ranging between 13 and 21 annual observations, such as Wang (2022) 13 periods; Li and Shao (2022) and Tujo (2021) 20 periods; Xhindi et al. (2020) 21 periods. This illustration can justify the application of ARDL to our study for which we only have 20 observations to conduct our regression.

The ARDL cointegration procedure consists of two steps. The first step is to examine the existence of a long-run relationship between the variables in the model. In the second step, if cointegration exists, the long-run and short-run coefficients are estimated using ARDL and error correction models (ECM).

The unrestricted error correction term for the general model mentioned in Eq. (3) can be specified as follows[2]:

$$\begin{aligned}\Delta lnEPv_t &= \beta_0 + \beta_1 DU + \sum_{i=0}^{p}\delta_1\Delta lnEPv_{t-i} \\ &\quad + \sum_{i=0}^{q}\delta_2\Delta lnHYDRO_{t-i} + \sum_{i=0}^{r}\delta_3\Delta lnDE_{t-i} \\ &\quad + \sum_{i=0}^{s}\delta_4\Delta lnGDP_{t-i} + \sum_{i=0}^{z}\delta_5\Delta lnREER_{t-i} \\ &\quad + \theta_1 lnEPv_{t-i} + \theta_2 lnHYDRO_{t-i} \\ &\quad + \theta_3 lnDE_{t-i} + \theta_4 lnGPD_{t-i} \\ &\quad + \theta_5 lnREER_{t-i} + \varepsilon_{1t},\end{aligned} \tag{3}$$

where DU is the dummy variable assigned following the structural breakpoint of our dependent variable. The terms θ describe the long-run effects while the first difference terms (Δ) describe the short-run relationship between EPv and HYDRO. The DE, GDP, and REER variables remain unchanged. (p, q, r, s, z) are the respective lags of each variable.

Data

The data used in this study are from secondary sources. They include electricity price (EP) (low-voltage electricity tariffs for households), share of hydropower in the total electricity generation mix (GWh), GDP growth (GDP) (annual %), real effective exchange rate index (2010 = 100), electric power demand (final electricity consumption, GWh). This study focuses on the period from 2000 to 2019, a time frame chosen due to the absence of longer data for Cameroon. Data on the share of hydropower in the total electricity generation mix and electric power demand are taken from the Energy Statistics Data Browser—(IEA, 2023). GDP and REER are from the World Development Indicators (WDI, 2023) DataBank). Data on electricity tariffs for households (domestic and other users) were obtained from electric tariff decisions published on the "Agence de régulation du secteur de

[2] This approach has already been used by Pesaran et al (2001) to estimate the wage equation in the UK, among other works.

Table 2 Results of the stationarity tests

Variables	ADF		PP		KPSS	
	No trend	With trend	No trend	With trend	No trend	With trend
ln_HYDRO	−0.251 (0.9321)	−3.221 (0.0802)	−0.308 (0.9244)	−3.681** (0.0237)	1.01*	0.151**
D.ln_HYDRO	−5.671* (0.0000)	−5.363* (0.0000)	−5.804* (0.0000)	–	–	–
ln_DE	−1.306 (0.6262)	−1.248 (0.9002)	−0.883 (0.8317)	−1.937 (0.6354)	0.878*	0.165**
D.ln_DE	−3.181** (0.0211)	−3.876 ** (0.0429)	−5.583* (0.0000)	−5.824* (0.0000)	–	–
Ln_GDP	−2.410 (0.1390)	−2.017 (0.5920)	−2.968 (0.0580)	−2.907 (0.1599)	0.401**	0.127
D.ln_GDP	−4.265* (0.0005)	−3.834** (0.0149)	−5.785* (0.0000)	−5.724* (0.0000)	–	0.211**
ln_REER	−1.963 (0.3028)	−3.157 (0.0933)	−2.426 (0.1346)	−3.217 (0.0811)	0.5**	0.256*
D.ln_REER	−3.187** (−3.400)	−3.314** (0.0341)	−4.488* (0.0002)	−4.539* (0.0013)	–	–
ln_EPv	−1.857 (0.3523)	−1.692 (0.7542)	−1.923 (0.3215)	−1.756 (0.7258)	0.210	0.308*
D.ln_EPv	−3.981* (0.0015)	−3.960** (0.0100)	−3.985* (0.0015)	−3.961** (0.0100)	0.474**	–

Source: Authors

ADF augmented Dickey–Fuller test, *PP* Phillips–Perron, *KPSS* Kwiatkowski–Phillips–Schmidt–Shin test for stationarity

* and ** refer to the 1% and 5% significance level, respectively

l'électricité—Cameroon" (ARSEL, 2022) website. All variables' selections were based on theoretical foundations and existing literature.

Results

Preliminary analysis of data

Table 1 presents the descriptive statistics of the variables analyzed. The results show significant volatility in electricity prices, with a mean of 0.387 and a standard deviation of 2.235 for ln EPv. With regard to the variable HYDRO, the average of 4170.85 GWh and a standard deviation of 564.388 appears consistent with electrical power measurements, indicating a significant hydroelectric energy production capacity. This result could potentially explain the high concentration of this energy source in the country's energy mix. The variable DE exhibits significant variability, with an average of 4574.3 GWh and a standard deviation of 1325.502. As for the economic growth rate, the mean of 4.186 and standard deviation of 1.196 indicate relative stability, although year-to-year variations are present. Finally, the REER shows relative stability, with a mean of 99.42 and a standard deviation of 3.543. Except for HYDRO, GDP and REER, the distribution of the data is normal and negatively skewed. In summary, these results highlight substantial electricity price volatility, significant variation in electricity consumption, relatively stable economic growth but subject to fluctuations, and relative stability in the real effective exchange rate.

To analyze the link between electricity price volatility and renewable energy production, we conduct an empirical analysis, giving unit root findings to examine the stationarity qualities of the variables employed. The traditional augmented Dickey–Fuller, Phillips–Perron tests, and Kwiatkowski–Phillips–Schmidt–Shin test for stationarity were used to accomplish the unit root test. The results in Table 2 reveal a combination of stationary I(0) and nonstationary I(1) for the variables at 1 and 5 and 10% significant levels for drift and drift with trend.

Table 3 Results of the Zivot and Andrews unit root test

Variables	ZA		
	Level	Breakpoint	Lag
ln_HYDRO	−4.392	2012	0
ln_DE	−5.003**	2006	0
ln_REER	−3.907	2010	0
ln_GDP	−4.508	2012	0
ln_EPv	−3.844	2012	0
Exact critical value			
1%	−5.34		
5%	−4.80		
10%	−4.58		

Source: Authors

ZA Zivot and Andrews unit root test

* and ** denote 1% and 5% significance levels, respectively

Table 4 PSS bounds test results

Dependent variable: Ln_EPv					
Model	F-statistic	6.448			*P*-value
	Value	10%	5%	1%	
	I(0)	3.102	4.021	6.642	0.011
	I(1)	4.627	5.872	9.357	0.037

Source: Authors

Table 5 Criteria for the optimal choice of delay

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	33.5682		1.9e-08	−3.57102	−3.55866	−3.32959
1	81.4752	95.814	1.3e-09	−6.4344	−6.36022	−4.98579
2	149.274	135.6	2.5e-11*	−11.7843	−11.6483	−9.12851
3	2497.31	4696.1		−302.163	−301.965	−298.3
4	2547.46	100.3*		−308.432*	−308.234*	−304.569*

Source: Authors

LR sequential LR test statistic (each test at 5% level), *FPE* final prediction error, *AIC* Akaike Information Criterion, *SC* Schwarz Information Criterion, *HQ* Hannan–Quinn Information Criterion

* indicates optimal lag

Table 6 Diagnostic tests

	Statistics	Prob	Decision
Breusch–Godfrey LM test	0.174	0.6861	No serial correlation
Breusch–Pagan test for heteroskedasticity	0.87	0.3509	Constant variance
White's test	19.00	0.3918	Homoskedastic
Histogram-normality test	1.567	0.4569	Normally distributed
Cumulative sum test for parameter stability	0.2206	0.9479	Structural break

Source: Authors

Table 3 presents the results of the Zivot and Andrews unit root test for the null hypothesis of a unit root with a structural breakpoint. Except for power demand, the results suggest that the unit root cannot be disregarded for the models. We inserted a dummy variable based on the dependent variables (DU). The mixture of I(0) and I(1) is confirmed by unit root tests. As a result, the cointegration process is used to determine if the variables have a long-term connection.

The limits test of the connection in level is presented in Table 4. The estimated F-statistic for the supplied pricing model is more than the crucial threshold of 5% significance, meaning that the null hypothesis of no long-run coefficient cannot be accepted.

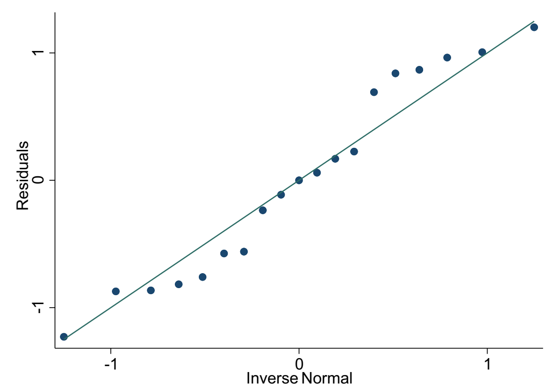

Fig. 2 Assessing the normality of residuals: standardized normal probability

Impact of hydroelectric generation on electricity price volatility

To estimate the impact of hydroelectric generation on electricity price volatility, we use the ARDL model to some diagnostic tests. The model passed the test for serial correlation, autocorrelation, heteroscedasticity, and normality. In addition, the plot of the fitted and actual values shows a similar trajectory as "two weights in a pod", suggesting that the model is well-fitted.

Table 5 presents the results of a time series analysis with different lags. The results show that the optimal lag would be four for this time series analysis.

Table 6 presents the results of diagnostic tests conducted on the residuals of a time series analysis to check specific conditions such as serial correlation, heteroskedasticity, normality, and structural stability. We use the Breusch–Godfrey LM test to examine the serial correlation in the residuals, and the results show a p-value of 0.6861 (> 0.05), indicating that there is no evidence of significant serial correlation in the residuals. Furthermore, we use the Breusch–Pagan test to examine the heteroskedasticity, where the null hypothesis suggests homoskedasticity. The results show a p-value of 0.3509 (> 0.05),

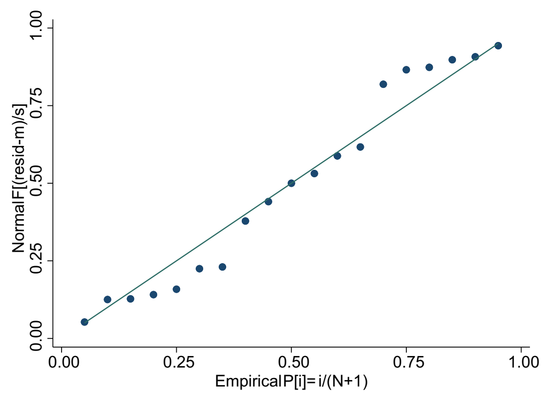

Fig. 3 Histogram-normality test: quantiles of residuals vs quantiles of normal distribution

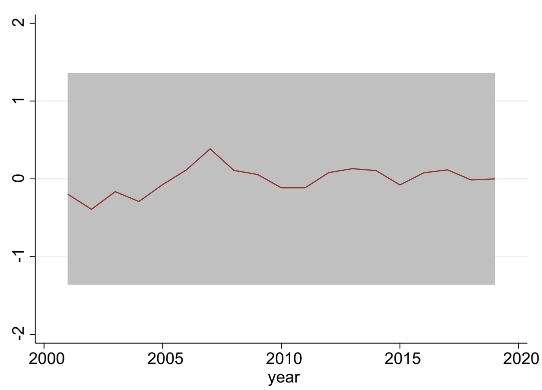

Fig. 4 Detecting structural breaks in D.ln_EPv: OLS CUSUM Plot with 95% confidence bands

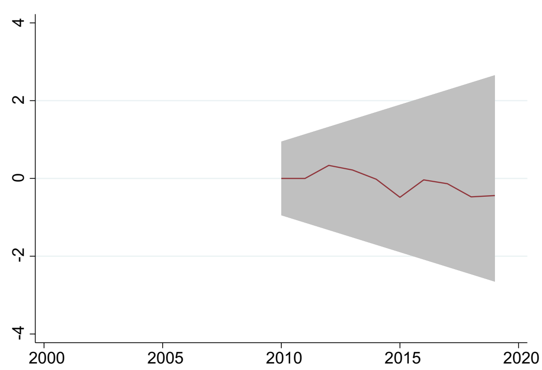

Fig. 5 Detecting structural breaks in D.ln_EPv: recursive CUSUM Plot with 95% confidence bands

indicating that the null hypothesis is not rejected, and there is no evidence of heteroskedasticity. We use also the White's test to detect homoskedasticity in the residuals, and the results show a p-value of 0.3918 (>0.05), indicating that there is no evidence of heteroskedasticity.

Table 7 Regression results of the ARDL model (1,1,1,0,0)

ln_EPv	**Coefficient**	**Std. err.**	***t***	***P*>*t***
D(ln_EPv)	0.360**	0.143	2.510	0.031
D(ln_HYDRO)	−1.218	5.986	−0.200	0.843
D(ln_HYDRO(−1))	17.469**	6.549	2.670	0.024
D(ln_DE)	−3.612	4.125	−0.880	0.402
D(ln_DE(−1))	−4.329	4.034	−1.070	0.308
D(ln_GDP)	2.929**	1.016	2.880	0.016
D(ln_REER)	−20.623*	9.775	−2.110	0.061
DU	−2.068	1.235	−1.670	0.125
Constant	22.555	70.347	0.320	0.755
F-statistic	9.57			
Prob > *F*	0.0009			
R-squared	0.8845			
Number of obs	19			

Source: Authors

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The histogram-normality test used checks whether the residuals follow a normal distribution (Figs. 2 and 3). The results show that the *p*-value is 0.4569 (>0.05), indicating that the null hypothesis of normality is not rejected. Finally, we use the cumulative sum test for parameter stability to detect whether there is a structural break in the model. The results show a *p*-value of 0.9479 (>0.05), indicating that there is no evidence of a structural break (Figs. 4 and 5).

In light of the results of the diagnostic tests, we can infer that the residuals meet the linear regression model's assumptions, which include the residuals being normally distributed with constant variance and no significant serial correlation or structural breaks.

Table 7 provides the short-term estimates. Previous year price volatility (i.e., lag 1) has a significant positive effect on current price volatility. The share of hydro generating has an immediate favorable influence on the uncertainty of power prices. This effect increases in the following period and then decreases. Overall, increasing the amount of hydro in overall energy production increases the total variation of electricity costs in Cameroon over time in the short term. This supports the prior literature's contention that growing renewable energy generation increases price volatility in the power system. This result corroborates the results obtained by Pereira da Silva and Horta (2019) and Owolabi et al. (2023). It lends credence to the notion that hydropower helps to the order and merit effect. Power plants have a low marginal cost. As a result, they may provide cheaper power in the retail sector, which consequently lowers electricity bills.

Economic growth has a considerable positive influence on the variation of power prices; the effect grows overall,

Table 8 Regression results of the ARDL-ECM model (1,1,0,0,0)

D.ln_EPv	Coefficient	Std. err.	*t*	*P* > *t*
ECT	−0.640***	0.143	−4.470	0.001
Long-run estimate				
ln_HYDRO	25,390 *	11.817	2.150	0.057
ln_DE	−12.407**	4.664	−2.660	0.024
ln_GDP	4.576**	1.675	2.730	0.021
ln_REER	−32,222 *	15.638	−2.060	0.066
Short-run estimation				
D.ln_HYDRO	−17.469**	6.549	−2.670	0.024
D.ln_HYDRO	4.329	4.034	1.070	0.308
DU	−2.068	1.235	−1.670	0.125
cons	22.555	70.347	0.320	0.755
R-squared	0.7971			
Number of obs	19			

Source: Authors

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

and growing economic growth increases electricity price volatility in the near term. In the near term, the effect of energy demand on price volatility is negative, but not statistically significant. Instead, in the short run, the real exchange rate has a negative impact on the volatility of electricity prices.

Table 8 presents the results on the estimated error correction model (ECM), which include a substantial and negative coefficient for the error correction term (ECT), reinforcing the long-run equilibrium relationship conclusions. In the near term, the percentage of hydropower affects electricity prices. In the near term, increasing the amount of hydropower raises household energy costs. In the long run, however, the situation is different since the long-term impact of hydropower production on electricity prices is notably favorable, and the effect is not particularly elastic. All else being equal, a 10% increase in hydropower share results in a 253.90% reduction in electricity price in the long run, according to the estimate. Overall, the increased use of hydro-based renewable energy raises power prices in the long term. The differential effects of hydropower share on electricity price in the short and long-term support the idea that the relationship between electricity price and hydropower is dynamic. The present research, like Adom et al. (2018), finds that the association is dynamic. It varies from their work in that it demonstrates that the negative impacts of hydropower on electricity prices are just a short-term occurrence, not a long-term issue.

Cameroon's power supply chain is expected to be enhanced by a collective pooling of XAF 40 billion among around 700 small and medium-sized enterprises (SMEs) and small and medium-sized industries (SMI). This amount is equal to the annual income generated by small and medium-sized enterprises in Cameroon's power subcontracting industry, according to a recent statement by Eneo Cameroon (2022). Since the growth in renewable energy (hydro) production, as shown in our data, lessens the volatility of power costs in the near term, it would be sensible to promote SME engagement in this area. Thus, content policy and other government and stakeholder actions that foster an SME-friendly climate are more likely to encourage SME involvement in Cameroon's energy industry. Establishing a local manufacturing chain for electrical materials and equipment that is now imported would improve the participation of local enterprises in the power industry.

In the short term, the REER has no inflationary influence on the price of power. This is due to the power regulatory ARSEL adjusting the pass-through impact of REER depreciation to Cameroon's electricity rates. However, the depreciation of the local currency has a deflationary effect on the price of electricity in the long run. In the long term, a 1% rise in the REER results in a 32.22 percent decrease in the variable price of energy. Cameroon relies heavily on foreign fuels to generate energy. This implies that, even if fuel prices do not change on the worldwide market, a weakening of the local currency would lower the cost of fuel in real terms, lowering the cost of production and, as a result, increasing the availability of power. Given the proportion of their entire budget allocated to power usage, the overall result is that electricity prices may be reduced, thereby improving family welfare.

GDP has an immediate positive effect on EPv. The emergence of cheap, reliable electricity sparked a worldwide economic paradigm shift. Reduced economic growth and private investment are direct results of inadequate power generation. The aluminum industry is a good example of a sector whose growth is tied to the availability of new energy sources. The long-term effect of GDP on EPv is significantly positive and highly elastic. According to the estimate, a 10% increase in growth, in the long run, will lead to an increase in the price of electricity of about 45.76%. Thus, overall, an increase in growth imposes a higher cost of electricity on consumers.

The results presented in Table 8 corroborate the hypothesis of demand elasticity about price. There is a statistically significant and negative relationship between electricity demand and price volatility in the long term. When power demand rises by only 1%, price volatility decreases by 12.4%. This demonstrates the flexibility of the power market. Because of this, electricity is considered a luxury item in Cameroon. Despite its enormous hydraulic potential, which accounts for 75% of energy generation, Cameroon is unable to fulfill the demand for electricity from enterprises. The shortage of power generation severely hampers the expansion of business and personal investment. The public sector, low and medium voltage (550,000 customers, with a peak demand of 550 MW), and high-voltage industrial sector all contribute to the need for energy. The major user in this second sector is the aluminum manufacturing company ALUCAM, which is contemplating increasing its production capacity, which would boost its electricity use to 520 MW. Other small and medium-sized (SME) businesses urgently need an extra 340 MW of electricity so they can grow shortly. According to Eneo, just 15 enterprises account for 65% of this demand. Here are some examples: Prometal IV, Sky Hotel, SAD Bonapriso, GeoRessource, EverWell, CFAO Retail, Cemtech, Prometal, Novia, Zhenglong, Bocom, SAD Japoma, Cimencam, Mira 1&2 et de Sosucam. Agribusiness, cement, real estate, and services are the most in-demand industries.

Conclusion and policy implications

This study has examined the short- and long-term impacts of various factors on the volatility and price of electricity in Cameroon, a country that relies heavily on hydroelectric power generation and foreign fuels to generate energy. The study's results provide insights into the relationship between renewable energy production, economic growth, energy demand, exchange rates, and GDP in the Cameroonian electricity market, which can inform policymakers, energy regulators, and private investors in making decisions that contribute to the efficient and sustainable development of the country's electricity market. In addition, the results obtained showed that improving the power supply chain and encouraging SME engagement in the renewable energy sector reduce the volatility of electricity prices and provide an opportunity for local enterprises to participate in the power industry. Motivated by the need to tackle the challenges facing by the Cameroon's electricity market, our study aimed to make a significant contribution to the country's overall sustainable development and economic growth.

The ARDL model was used to estimate the long-run and short-run elasticity coefficients of the variance of electricity price volatility to renewable energy production. The result of the study reveals both positive and negative aspects of various factors that impact on the volatility and price of electricity in Cameroon.

On the positive side, hydropower generation has an immediate favorable effect on the uncertainty of power prices and can lead to a notable reduction in electricity prices in the long run. This suggests that the increased use of hydro-based renewable energy can improve the overall efficiency and sustainability of the Cameroonian electricity market. Additionally, economic growth was found to have a considerable positive impact on the variation of power prices, highlighting the potential benefits of improving the economy and private investment through increased power generation.

On the negative side, the study found that in the short term, increasing the amount of hydro in overall energy production increases the total variation of electricity costs in Cameroon. Energy demand also has a negative and insignificant effect on price volatility over the short term, indicating that there may be challenges in meeting the needs of enterprises that urgently require additional electricity for growth. Furthermore, the study found that electricity prices in the long run would be highly affected by exchange rates, which may not be within the control of the electricity market. However, the study suggests that the depreciation of the local currency could lower the cost of fuel in real terms, thereby reducing the cost of production and improving the availability of power.

Furthermore, the results suggest that the use of hydro-based renewable energy has both positive and negative impacts on the volatility and price of electricity in Cameroon. In the short term, increasing the share of hydropower in overall energy production increases the total variation of electricity costs. However, this impact becomes significantly favorable in the long term. The study also found that economic growth has a considerable positive impact on the variation of power prices, as improving power generation can stimulate economic growth and private investment. The study suggests then that promoting SME engagement in renewable energy production and establishing a local manufacturing chain for electrical materials and equipment are strategies that can improve the participation of local enterprises in the power industry and reduce the volatility of electricity prices. However, the results obtained showed that the impact of exchange rates on electricity prices may not be within the control of the electricity market, but could be mitigated by the depreciation of the local currency. Overall, the study provides a basis for understanding the complex interplay between various factors and their impacts on the Cameroonian electricity market.

The future implications of this study are significant for policymakers, energy regulators, and private investors in Cameroon's power industry. The study's results inform policymakers on the need to develop a sustainable energy policy that balances the short-term impacts of hydropower generation on electricity costs with the long-term favorable impacts. Encouraging SME engagement in the renewable energy sector and establishing a local manufacturing chain for electrical materials and equipment to reduce the dependence on imported products also has important implications for the country's future energy security. The results obtained in this study emphasized that economic growth has a considerable positive impact on the variation of power prices and highlighted then the need for the Cameroonian government to prioritize power generation to stimulate economic growth and private investment.

Furthermore, the results obtained have also implications for future research in the field of renewable energy and electricity markets. For instance, the future researches can further explore the dynamic relationship between renewable energy generation and price volatility, and investigate the effectiveness of policies, such as feed-in tariffs or net metering, promoting renewable energy production and reducing price volatility.

Finally, the study's future implications could be centered around the need to develop a sustainable and efficient energy market that can support the overall economic growth of Cameroon and provide stable and affordable electricity for its citizens.

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Author contributions
EBA: conceptualization, methodology, software, validation, writing—original draft. VCK: conceptualization, methodology, writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
As this study did not involve any human or animal subjects, ethics approval and consent to participate are not applicable.

Consent for publication
By submitting this manuscript to Springer Nature, I confirm that all authors have approved the final version of the manuscript, and we are aware that the journal's editorial team will evaluate the content for potential publication. Furthermore, by submitting this manuscript, we confirm that the work is original, does not infringe any third party intellectual property rights, and is not under consideration or published elsewhere.

Competing interests
The authors declare no competing interests. We confirm that we have disclosed all potential conflicts of interest to the journal, including financial, personal, or other relationships that could appear to influence the work.

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