

## **Residential Electricity Consumption in Cameroon: Access to Electricity at the Heart of Explanatory Factors using the ARDL Model**

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### **ABSTRACT**

This study analyses the influence of power availability in both urban and rural locations on residential electricity consumption in Cameroon. The analysis is based on annual data covering the period 2000-2022. An ARDL model examines the short- and long-term relationships between residential electricity consumption, power availability in both urban and rural locations, living standards and industrial value added. The Toda-Yamamoto causality test is used to determine the direction of the relationships between the variables. The results highlight the existence of a long-term equilibrium relationship between access to electricity and residential electricity consumption. In the short term, access to electricity in rural areas has a positive and statistically significant effect on consumption, while urban access is associated with a decrease in residential consumption. In the long term, access to electricity appears to be a necessary but not sufficient condition for stimulating sustainable consumption, which remains strongly influenced by socio-economic and structural factors. These results suggest that electrification policies must go beyond simply extending the grid, incorporating measures to improve the reliability of supply, affordability and household purchasing power. Such an approach is essential to reduce urban-rural disparities and promote more productive and sustainable use of electricity in Cameroon. This study is the first of its kind in Cameroon to empirically analyse the relationship between household electricity consumption and access to electricity, in both urban and rural areas.

**Keywords:** Access to Electricity, Residential Electricity Consumption, Urban and Rural Areas, ARDL Model, Cameroon

**JEL Classifications:** C01, C51, D63, Q40

## **1. INTRODUCTION**

Access to electricity is central to economic and social development strategies, particularly in developing countries where energy deficits remain significant. Electricity is an essential factor in the functioning of productive activities, health and education services,

and the improvement of household living conditions (Alegre-Bravo and Lindsay Anderson, 2023). It promotes the adoption of new domestic uses, supports productivity and accompanies structural transformations in economies (Ongo Nkoa et al., 2023; Oseni, 2012). However, improved access to electricity does not always translate into a significant increase in energy consumption,

particularly in the residential sector. This situation highlights the existence of economic, social and institutional constraints that limit the intensity of energy use beyond simple connection to the grid. Therefore, a joint analysis of access to electricity and energy consumption appears essential to assess the effectiveness of electrification policies, to better understand household energy behaviour and to guide development and energy transition strategies.

In sub-Saharan Africa, the issue of access to electricity is particularly evident in its limited impact on actual energy consumption. Several major investments have been made in recent years by donors such as the World Bank and several European countries to expand electricity networks and increase connection rates, totalling more than \$1 billion. Despite these efforts, per capita electricity consumption remains among the lowest in the world (Byaro and Mmbaga, 2022). This situation highlights a structural gap between the availability of the grid and its actual use. As pointed out by Gamette et al. (2024), this gap cannot be explained solely by the lack of infrastructure, but also by constraints in terms of affordability, quality of connectivity and the existence of technically connectable populations that remain excluded from electricity services or limit their use, mainly for cost reasons.

Furthermore, the particularly marked inequalities in access between urban and rural areas (17% vs. 59%) translate directly into significant differences in energy consumption (Gamette et al., 2024; Trotter, 2016). However, even in areas with formal access to electricity, consumption volumes remain low, indicating that simply connecting to the grid does not automatically lead to increased consumption (Lahnaoui et al., 2024). Access to electricity thus appears to be a necessary but insufficient condition for stimulating energy consumption, which remains constrained by economic, social and structural factors. These factors highlight that the relationship between Sub-Saharan Africa's energy use and power accessibility is complex and non-linear, and that a joint analysis of access and use is essential to guide electrification policies and energy development strategies.

Cameroon perfectly illustrates these structural challenges. The national electrification rate has increased significantly, from around 40% in the early 2000s to over 70% in 2022 (Jacques Fotso et al., 2023). This progress reflects sustained efforts in terms of infrastructure, but it masks persistent inequalities, with access often exceeding 90% in urban areas compared to around 30% in rural areas (Ayuketah et al., 2023). At the same time, residential electricity consumption remains relatively low. It stood at around 256 kWh per capita in 2019, well below regional and global averages (AIE, 2024). These data raise questions about the nature, intensity and very existence of a direct link between access to electricity and household energy consumption, highlighting the importance of considering infrastructure, affordability and usage patterns in the country's energy analysis.

Despite the relevance of this issue for energy policies, empirical literature remains limited on the dynamic analysis of this relationship, particularly in the Cameroonian context. Existing

work by Guefano et al. (2023), Tamba et al. (2017) and Tokam and Ouro-Djobon (2025), often focus on aggregate macroeconomic determinants without differentiating the effects according to the place of residence or exploring short- and long-term adjustments. However, in transition economies marked by structural rigidities, these relationships may prove to be non-linear and evolving.

This study provides a robust analytical framework to guide energy policies in Central Africa, particularly in Cameroon, and to enrich future research on residential demand in developing countries. A first gap identified in the literature concerns the absence of a structured theoretical framework for rigorously analysing the relationship between access to electricity and energy consumption in the residential sector. This lack of conceptual foundation limits the internal consistency of existing empirical work and restricts its ability to effectively inform public policy, as well as to produce reliable projections of residential energy consumption.

This study differs from the existing literature in its innovative approach, which explicitly integrates Power accessibility in both rural and urban areas as key explanatory variables for energy consumption in the residential sector. The main contribution lies in the simultaneous introduction of these two territorial dimensions as socio-economic factors likely to influence residential energy consumption levels. The results thus provide a relevant analytical framework for guiding public policy and furthering future academic research.

Another major contribution of this study is the joint analysis of short- and long-term relationships, as well as the causal links between residential electricity consumption, access to electricity in urban and rural areas, GDP per capita and industrial value added. This integrated approach is particularly relevant given that public decision-makers are interested in both immediate effects and long-term structural dynamics. As such, the study provides lessons that can be directly applied to the development of energy policies in developing countries, particularly those in Central Africa.

The remainder of the investigation is organized as follows: A review is given in Section 2 of the literature review. The third section details the facts used and the methodology adopted. The fourth section the main empirical outcomes. Section 5 establishes an in-depth conversation, while the end of Section 6 the analysis and makes policy recommendations.

## 2. BRIEF REVIEW OF THE LITERATURE

### 2.1. The Relationship between Access to Electricity and Residential Energy Consumption

The literature on development examines access to electricity as a potential determinant of energy consumption, while highlighting highly contrasting empirical results. Conceptual approaches argue that access to reliable electricity services shapes modern energy use and supports economic and human development trajectories (Reddy, 2015). Empirically, numerous study highlight a positive outcome of access to electricity on the use of power, particularly in Brazil, where improved access is associated with a significant increase in domestic and productive consumption (Lipscomb et al.,

2013), in Ghana, where increased access rates have led to higher per capita electricity consumption (Yawa, 2023), and in certain African contexts where households have sufficient economic capacity (Oseni, 2012). However, other studies have produced more nuanced, even limited results. Mika et al. (2021) analyse energy access (including electricity) and household consumption patterns, showing that access does not necessarily translate into increased modern consumption or direct economic benefits; Bernard (2012), in the case of Ethiopia, highlights the low impact of access to electricity on modern energy use. Finally, Lee et al. (2020) show that, in several sub-Saharan African countries, access to electricity leads to a modest increase in consumption, which is insufficient to bring about a lasting transformation in energy profiles in the absence of productive capacity. Taken together, these studies suggest that access to electricity can support energy consumption in a development process, but that its effect is closely dependent on economic, productive and institutional conditions, thus explaining the lack of clear consensus in the literature.

The review of the empirical literature highlights the still limited nature of studies analysing the direct link between access to electricity and energy consumption in the residential sector, particularly in the Cameroonian context. Existing studies highlight significant disparities between urban and rural areas, where electrification levels often remain insufficient to support significant energy consumption, while few studies systematically integrate these dimensions simultaneously. To date, no specific empirical verification has been carried out considering jointly Power supply in both rural and urban areas and its effects on household consumption in Cameroon. This gap constitutes a significant scientific void, justifying the need for an in-depth analysis aimed at better understanding the mechanisms linking access to electricity to residential energy consumption. With this in mind, this study adopts a comparative approach between urban and rural areas, integrating electricity coverage, grid reliability, availability of domestic equipment and the socio-economic status of households, in order to evaluate the concrete effect of having a supply of power on energy consumption, while providing useful information to guide public policies for the extension and improvement of electricity services in Cameroon.

## 2.2. Relationship between Energy Consumption and Industrialisation

The expansion of industrialisation is generally accompanied by sustained growth in energy demand. Indeed, the operation of the various equipment and infrastructure necessary for the production of goods requires significant amounts of energy, making this sector a key driver of national energy consumption. As a result, industrialisation tends to increase energy intensity, reflecting a greater dependence of the productive system on energy resources (Poumanyong and Kaneko, 2010). Based on a panel of 76 developing countries, including Tunisia, over the period 1980-2012, the study by Keho (2016) highlights that a higher level of industrialisation tends to increase energy intensity in both the short and long term. More recently, the study by Canh et al. (2021) reinforces the previous findings by confirming the existence of a positive link between industrialisation and energy intensity in developing countries. This relationship can be explained in

particular by the phenomenon of relocation; energy-intensive industries, often seeking lower production costs and less stringent environmental regulations, tend to set up in these countries. Although this industrial transfer supports local economic growth, it leads to a significant increase in energy consumption in both the short and long term.

In contrast to the findings establishing a positive relationship between industrialisation and energy consumption, the study Kebede et al. (2010) conducted on a sample of 20 sub-Saharan African countries highlights an inverse correlation. According to the authors, this trend can be explained by a gradual transformation of economic structures, where modernising industry becomes less energy-intensive than traditional agriculture. In particular, the introduction of more efficient and automated irrigation systems contributes to a more rational use of resources. In addition, industrial companies tend to adopt more efficient technologies, which not only reduces production costs but also limits energy consumption, thereby improving the sector's overall energy performance. In the case of Ghana, Adom et al. (2012) highlight a significant correlation between improved industrial performance and lower electricity consumption. This dynamic is explored in greater depth by Asgari (2020), who introduce an interaction variable combining periods of energy reform with manufacturing value added. Their results highlight a mitigating effect on energy demand, suggesting that public policies, particularly tariff incentives, have effectively curbed excessive fuel use. Furthermore, subsequent studies emphasise the decisive impact of intra- and inter-sectoral productive reallocations in industry, which promote greater energy efficiency and contribute to the transition towards more rational consumption.

## 2.3. The Relationship between Energy Consumption and Economic Growth

From a theoretical perspective, research identifies four major hypotheses aimed at interpreting the causal link between increased economic activity and energy demand (Ozturk, 2010). The feedback hypothesis suggests the existence of an interdependent relationship between energy consumption and national income. In other words, not only does economic growth influence energy demand, but the reverse is also true. The availability and use of energy have a significant effect on income levels. Studies such as Apergis and Payne (2009), Baz et al. (2019) and Magazzino et al. (2021) have highlighted this bidirectional dynamic, indicating that an effective energy policy cannot be devised without taking into account its economic impact, and vice versa. This approach therefore emphasises the importance of an integrated strategy between energy development and economic growth. The second hypothesis, known as the growth hypothesis, is based on the idea that energy consumption is a key driver of economic development. According to this perspective, increased energy use, particularly in productive sectors, stimulates GDP growth by improving productivity, facilitating industrial activities and strengthening production capacities. Unlike the feedback hypothesis, here the causality is unidirectional, flowing from energy to the economy. Several empirical studies such as Wolfe-Rufael (2005) and He et al. (2017) support this view by demonstrating that in many countries, particularly developing countries, any disruption or

restriction in energy supply can slow down the pace of growth. This hypothesis therefore argues for sustained energy policies and constant investment in energy infrastructure as essential levers for economic development. A third approach, known as the conservation hypothesis, posits that growth in the economy is what influences Energy use, and not reverse. In other words, an increase in GDP leads to an increase in energy consumption, but this relationship is unidirectional; the economy can grow independently of an expansionary energy policy.

According to this perspective, policies to reduce or manage energy consumption would not necessarily harm growth, paving the way for energy conservation strategies without compromising economic performance. Empirical studies, such as those by Pinzón (2018), Faisal et al. (2016) and Mutascu (2016) argue that in certain contexts, particularly in economies where energy efficiency is improving and where the tertiary sector dominates, growth can continue even while limiting energy use. This interpretation offers interesting scope for decision-makers engaged in energy transition, emphasising the importance of technological innovation and modernisation of productive sectors to decouple energy from growth. Finally, the neutrality hypothesis suggests that there is no significant causal relationship between energy consumption and economic growth. In other words, neither does increased energy consumption necessarily stimulate GDP growth, nor does economic growth automatically lead to increased energy demand. From this perspective, energy conservation or restriction policies would not have a major negative effect on economic growth, and conversely, economic expansion could occur without depending on a proportional increase in energy consumption. This hypothesis is often interpreted as a sign of a relatively diversified economic structure or one geared towards low-energy sectors. These results are observed in the work of Caraiani et al. (2015), Magazzino (2015) and Akkemik and Göksal (2012).

### 3. SOURCES OF DATA AND THE DESCRIPTION OF THE MODEL

#### 3.1. Sources of Data

The current study examines details across links Use of power in residential areas and several explaining components: Access to electricity in urban and rural areas, economic growth and the added value of industry in Cameroon. The analysis is based on annual data covering the period 2000-2022, chosen according to the availability of statistical data. The data comes mainly from the World Bank and the International Energy Agency, as summarised in Table 1.

In this table, residential electricity consumption is considered the dependent variable, while the other variables (access to electricity, GDP growth, industrial value added) serve as explanatory variables.

#### 3.2. Model Specifications

According to previous studies, various factors can influence energy consumption, including economic, social, environmental and institutional factors (Guefano et al., 2023). Theoretically,

Use of power in residential areas is sensitive being per capita income: a rise in this income tends to increase energy demand (Gritli and Charfi, 2023; Shahbaz and Lean, 2012). Furthermore, the industrialisation process also affects this consumption, both directly through the expansion of industrial activities and indirectly through increased employment and the associated energy needs (Gritli and Charfi, 2023). Access to electricity, meanwhile, acts as a fundamental amplifying factor. It induces direct demand by enabling the use of electrical appliances, heating systems and lighting solutions (Solarin, 2025). More significantly, it generates a socio-economic knock-on effect: by improving education, productivity and economic opportunities, electrification boosts per capita income. This process creates a virtuous circle in which increased access to electricity leads to a sustainable expansion of household energy needs, far beyond the simple provision of the service (Solarin, 2025). Thus, the model that captures the effect of access to electricity in urban and rural areas, the added value of industry and GDP per capita is written as follows:

$$REC_t = f(AEU_t, AER_t, IVA_t, PIBH_t) \quad (1)$$

Assuming a logarithmic relationship, in order to obtain reliable and consistent empirical results from Eq. (1) as recommended by Chen et al. (2023). This also facilitates the interpretation of results in terms of elasticity. The proposed model, which captures the long- and short-term impacts of access to electricity in urban areas, access to electricity in rural areas, industrial value added, and GDP per capita on renewable energy consumption in the residential sector in Cameroon, is as follows:

$$LREC_t = \eta_0 + \eta_1 LAEU_t + \eta_2 LAEZ_t + \eta_3 LIVA_t + \eta_4 LPIBH_t + \varepsilon_t \quad (2)$$

Where  $\eta_0$  and  $\varepsilon_t$  stand for the constant and the error term, accordingly.  $LREC_t$ ,  $LAEU_t$ ,  $LAEZ_t$ ,  $LIVA_t$  and  $LPIBH_t$  denote the natural logarithm of electricity consumption, access to electricity in urban areas, access to electricity in rural areas, the value added by industry and GDP per capita, respectively.

Before estimating the relationships between variables, it is essential to ensure that the data are stationary. Integrating non-stationary variables into a regression model can skew the results and lead to misinterpretations. To ensure the reliability of the analyses, this study applied three-unit root tests to assess the stationarity of the series over the period studied. These are the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979), the AZ test (Zivot and Andrews, 2002) and the Phillips-Perron (PP) test (Phillips and Perron, 1988). The use of multiple tests is recommended in the literature in order to strengthen the validity of the results, as highlighted by Ben Amara et al. (2025), Sama et al. (2023), Ewodo-Amougou et al. (2023) and Sama et al. (2025).

Once the stationarity of the data has been confirmed, the study moves on to estimating the relationships within the ARDL model. This method, widely used in econometrics, makes it possible to analyse long-term cointegration links between several variables and to assess the impact of exogenous variables on the endogenous variable, both in the short and long term (Daly et al., 2024; Kotsompolis et al., 2023; Xuan, 2025). The ARDL approach, as

described by Pesaran et al. (2001), consists of three main steps. The first step is to test for the existence of a long-term relationship using a cointegration test based on Eq. (3). If a stable relationship is detected, the long-term coefficients can then be estimated. The cointegration test by Pesaran et al. (2001) to assess the short- and long-term outcomes and carry out the different diagnostic to verify the model's stability is presented as follows:

$$\begin{aligned} \Delta LREC_t = & \eta_0 + \sum_{i=1}^p \eta_1 \Delta LREC_{t-i} + \sum_{i=0}^p \eta_2 \Delta LAEU_{t-i} \\ & + \sum_{i=0}^p \eta_3 \Delta LAER_{t-i} + \sum_{i=0}^p \eta_4 \Delta LIVA_{t-i} \\ & + \sum_{i=0}^p \eta_5 \Delta LPIBH_{t-i} + \vartheta_1 LREC_{t-i} + \vartheta_2 LAEU_{t-i} \\ & + \vartheta_3 LAER_{t-i} + \vartheta_4 LIVA_{t-i} + \vartheta_5 LPIBH_{t-i} + \varepsilon_t \end{aligned} \quad (3)$$

The values  $\eta_1 \dots \eta_5$  and  $\vartheta_1 \dots \vartheta_5$  refer to short-term and long-term effects, respectively.  $\Delta$  indicates the first difference operator,  $\varepsilon$  indicates the term of error, and  $\rho$  represents the number of lags of the variables.

According to Pesaran et al. (2001), the existence of lasting relationships between variables can be verified by comparing the value of the F statistic with the upper critical limits. If the calculated F statistic exceeds this upper limit, this indicates the presence of a long-term cointegration relationship between the variables in the model. Once this cointegration is confirmed, the ARDL framework can then be used to estimate both the long-term and short-term coefficients. Equation (3) is used to obtain the long-term coefficients. Then, in the final step of the process, the short-term coefficients are derived from equation (4), with the integration of the error correction model (ECM), which measures the speed at which imbalances are corrected to bring the system back to its long-term equilibrium.

$$\begin{aligned} \Delta LREC_t = & \eta_0 + \sum_{i=1}^p \eta_1 \Delta LREC_{t-i} + \sum_{i=0}^p \eta_2 \Delta LAEU_{t-i} \\ & + \sum_{i=0}^p \eta_3 \Delta LAER_{t-i} + \sum_{i=0}^p \eta_4 \Delta LIVA_{t-i} \\ & + \sum_{i=0}^p \eta_5 \Delta LPIBH_{t-i} + \Phi_i ECM_{t-i} + \varepsilon_t \end{aligned} \quad (4)$$

Where  $\phi_i$  is the long-term coefficient of equilibrium adjustment and  $\varepsilon_i$  is the expression for error. This study opted for the ARDL method rather than other approaches such as structural equation modelling (SEM) or panel analysis, due to its many advantages. Firstly, the ARDL model allows for the establishment of robust connections between short- and long-term variables, which is particularly useful for analysing the links between residential electricity consumption and its explanatory factors. Secondly, one of its great advantages is its flexibility: it accepts variables with different integration orders, whether they are stationary at level  $I(0)$ , in first difference  $I(1)$ , or a mixture of the two. In addition, ARDL allows the use of variable lags for each series, which makes the model more realistic. It is also based on dynamic adjustment logic (error correction model), which is ideal for exploring long-term relationships in time series. Finally, ARDL is particularly effective even with a small sample size, provided that there is only

one long-term equilibrium relationship between the variables in the model.

Pesaran et al. (2001) is approach is predicated on many crucial and essential presumptions, including that this errors must be independent of each other and normally distributed. In order to verify serial independence, the Breusch-Godfrey Serial test is used; to test the normality of errors, the Jarque-Bera test is used; and to examine heteroscedasticity, the Breusch-Pagan-Godfrey test is used. The method of Pesaran et al. (2001) based on an autoregressive structure is only valid when the structure is well specified; otherwise, poor specification leads to model instability. In accordance with Pesaran and Pesaran (1997), this study uses the CUSUM of squares (CUSUMSQ) and the CUSUM of recursive residuals (CUSUM) to explain omitted variable bias and test for series instability.

### 3.3. Causality in the Sense of Toda-Yamamoto

The existence of time series cointegration can imply Granger causality, which can be both one-way or two-way. As stated by Granger (1969), we cannot rely solely based on correlation measures when attempting to comprehend the links between many series of times. Indeed, some links can be insignificant and erroneous, implying the presence of independent, uncontrolled variables. Furthermore, cointegration alone does not demonstrate the causal and effect relationship series. Put differently, cointegration may be established, but the results must be double-checked by verifying causality.

This study uses Granger causality testing in the sense of Toda-Yamamoto, due to its effectiveness for stationary series of different orders. This test is mainly based on the modified Wald test, which circumvents the problems associated with the classic Granger test. The approach developed by Toda and Yamamoto (1995) adapts the VAR model by applying it directly to level series, thereby circumventing the risks associated with misidentifying the order of integration of the variables. The Granger causality test method follows a clear series of steps. First, the level of integration of the series is identified using stationarity tests. Next, the optimal number of lags for the VAR model is determined using the Schwarz information criterion (SIC). An extended VAR is then estimated by adding the maximum degree of integration observed in the series to the number of lags. Once the model has been adjusted, diagnostic tests are performed to verify its validity. Finally, a Wald test is applied to the first parameters of the model to verify the existence of a causal link, based on a Chi-square distribution. Determining the number of lags to include in the augmented VAR depends on the degree of integration of the series. In practice, for a stationary series in level, no additional lags are required in the standard test. However, for a series integrated of order 1 ( $I(1)$ ), an additional lag is introduced, and this principle extends to series of higher order. Thus, according to the methodology of the equations derived from the augmented VAR can be interpreted as expressions of Granger causality between the variables considered.

Model 1: Electricity consumption in the residential sector and access to electricity in urban areas

$$\begin{aligned}
 LREC_t &= \alpha_0 + \sum_{i=1}^d \alpha_{1i} LAEU_{t-i} + \sum_{j=k+1}^{dmax} \alpha_{1j} LAEU_{t-j} \\
 &+ \sum_{i=1}^p \lambda_{1i} LAER_{t-i} + \sum_{j=k+1}^{dmax} \lambda_{1j} LAER_{t-j} \\
 &+ \sum_{i=1}^p \eta_{1i} LIVA_{t-i} + \sum_{j=k+1}^{dmax} \eta_{1j} LIVA_{t-j} + \\
 &\sum_{i=0}^p \Gamma_{1i} LGDPH_{t-i} + \sum_{j=k+1}^{dmax} \Gamma_{1j} LGDPH_{t-j} + \varepsilon_{1t} \quad (5)
 \end{aligned}$$

Model 2: Electricity accessibility in urban areas and electricity consumption in the residential sector

$$\begin{aligned}
 LAEU_t &= \alpha_0 + \sum_{i=1}^p \alpha_{1i} LREC_{t-i} + \sum_{j=k+1}^{dmax} \alpha_{1j} LREC_{t-j} \\
 &+ \sum_{i=1}^p \lambda_{1i} AER_{t-i} + \sum_{j=k+1}^{dmax} \lambda_{1j} LAER_{t-j} \\
 &+ \sum_{i=1}^p \eta_{1i} LIVA_{t-i} + \sum_{j=k+1}^{dmax} \eta_{1j} LIVA_{t-j} + \\
 &\sum_{i=0}^p \Gamma_{1i} LGDPH_{t-i} + \sum_{j=k+1}^{dmax} \Gamma_{1j} LGDPH_{t-j} + \varepsilon_{1t} \quad (6)
 \end{aligned}$$

Electricity use in the residential sector cause Access to electricity in urban areas if  $\eta_{1i} \neq 0, \forall_i = 1, 2, \dots, k$  in Eq. (5). Access to electricity in urban areas Residential electricity consumption if  $\alpha_{1i} \neq 0, \forall_i = 1, 2, \dots, k$  in Eq. (6). There is a bidirectional causality between Access to electricity in urban areas if  $\eta_{1i} \neq 0$  and  $\forall_i = 1, 2, \dots, k$  respectively in Eq. (5) and Eq. (6). Finally, there is no causality between electricity consumption and the residential sector cause Access to electricity in urban areas if  $\eta_{1i} = \alpha_{1i} = 0$ , and  $\forall_i = 1, 2, \dots, k$  respectively in Eq. (5) and Eq. (6).

Model 4: Access to electricity in rural areas and electricity consumption in the residential sector

$$\begin{aligned}
 LAER_t &= \alpha_0 + \sum_{i=1}^p \alpha_{1i} LREC_{t-i} + \sum_{j=k+1}^{dmax} \alpha_{1j} LREC_{t-j} \\
 &+ \sum_{i=1}^p \lambda_{1i} LAEU_{t-i} + \sum_{j=k+1}^{dmax} \lambda_{1j} LAEU_{t-j} \\
 &+ \sum_{i=1}^p \eta_{1i} LAER_{t-i} + \sum_{j=k+1}^{dmax} \eta_{1j} LAER_{t-j} \\
 &+ \sum_{i=0}^p \Gamma_{1i} LIVA_{t-i} + \sum_{j=k+1}^{dmax} \Gamma_{1j} LIVA_{t-j} \\
 &+ \sum_{i=1}^p \vartheta_{1i} LGDPH_{t-i} + \sum_{j=k+1}^{dmax} \vartheta_{1j} LGDPH_{t-j} + \varepsilon_{1t} \quad (7)
 \end{aligned}$$

Model 5: Electricity consumption in the residential sector and value added by industry

$$\begin{aligned}
 LIVA_t &= \alpha_0 + \sum_{i=1}^p \alpha_{1i} LREC_{t-i} + \sum_{j=k+1}^{dmax} \alpha_{1j} LREC_{t-j} \\
 &+ \sum_{i=1}^p \lambda_{1i} LAEU_{t-i} + \sum_{j=k+1}^{dmax} \lambda_{1j} LAEU_{t-j} \\
 &+ \sum_{i=1}^p \eta_{1i} LAER_{t-i} + \sum_{j=k+1}^{dmax} \eta_{1j} LAER_{t-j} \\
 &+ \sum_{i=0}^p \Gamma_{1i} LAER_{t-i} + \sum_{j=k+1}^{dmax} \Gamma_{1j} LAER_{t-j} \\
 &+ \sum_{i=1}^p \vartheta_{1i} LGDPH_{t-i} + \sum_{j=k+1}^{dmax} \vartheta_{1j} LGDPH_{t-j} + \varepsilon_{1t} \quad (8)
 \end{aligned}$$

The parameters of models 3, 4 and 5 are interpreted in the same way as those of models 1 and 2.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Descriptive Statistics Results and Stationarity of Variables

#### 4.1.1. Descriptive statistics

Table 2 shows a test of the volatility of the variables using their standard deviation values. It appears that the residential electricity consumption, urban electricity access, rural electricity access, gross domestic product per capita and industry fluctuate little. Subsequently, Jarque-Bera probabilities tell us that the variables residential electricity consumption, gross domestic product per capita and industry are normally distributed in the model (Udamba and Yaçintaş, 2022). Only urban and rural access to electricity show contrary results, i.e. they are not normally distributed. To consider the variance of errors in an autoregressive manner under the opposite of past information, a heteroscedastic model will be adopted in the presence of ARCH effects. Finally, gross domestic product per capita has a higher mean than the other series in the model.

#### 4.1.2. Stationarity of variables

Table 3 presents the results of the Augmented Dickey-Fuller and Phillips-Perron unit root tests, which show that residential electricity consumption and industrial value added only become stationary after first differentiation, while urban electricity access, rural electricity access and gross domestic product are stationary in level. This finding indicates that none of the series examined are second-order integrated, which satisfies one of the essential conditions for estimating an ARDL model and allows us to unambiguously consider the existence of a cointegration relationship between the variables. Table 4, which reports the results of the Zivot and Andrews stationarity test with endogenous structural break, confirms these conclusions: the integration orders obtained remain consistent with those identified in Table 3, thus reinforcing the robustness of the stationarity diagnostics and the relevance of the econometric approach adopted.

### 4.2. Choice of Optimal Lag, Cointegration Test and Model Specification

#### 4.2.1. Choice of optimal lag, cointegration test

To determine the optimal lag for the ARDL model, we used the Akaike (AIC) and Schwarz (SIC) information criteria. The values reported in Table 5 converge towards the same result, namely that the most appropriate lag order is 1. This choice reflects the need to

**Table 1: An explanation of the data being studied**

Variables	Description	Unit of measurement	Source
REC	Electricity consumption in the residential sector	Gigawatt hour	AIE (2024)
AEU	Access to electricity in urban areas	% of urban population	WDI (2025)
AER	Access to electricity in rural areas	% of rural population	WDI (2025)
IVA	Value added by industry	% of GDP	WDI (2025)
PIBH	Gross domestic product per capita	Current US dollars	WDI (2025)

**Table 2: Descriptive statistics of variables**

Indicators	LREC	LAEU	LAER	LIVA	LPIBH
Mean	6.812794	4.358814	2.883116	3.264240	7.172432
Median	6.958448	4.471639	2.933857	3.269569	7.268014
Maximum	7.395169	4.550714	3.269569	3.356897	7.494375
Minimum	5.958425	2.240710	1.856298	3.135494	6.551366
Std. dev.	0.458018	0.467182	0.340722	0.062409	0.272171
Skewness	-0.653383	-4.309771	-1.387157	-0.289619	-1.221432
Kurtosis	2.101050	20.08584	4.958414	2.140413	3.386927
Jarque-Bera	2.410924	350.9631	11.05170	1.029639	5.862410
Probability	0.299554	0.00000	0.003982	0.597608	0.053333
Sum	156.6943	100.2527	66.31168	75.07752	164.9659
Sum sq. dev.	4.615176	4.801708	2.554017	0.085688	1.629695
Observations	23	23	23	23	23

**Table 3: Results of the Augmented Dickey-Fuller and Phillips-Perron stationarity tests**

Variables	Level		First difference		Decision
	ADF	PP	ADF	PP	
LREC	-2.48 (0.13)	-2.47 (0.13)	-6.27*** (0.00)	-6.27*** (0.00)	I (1)
LAEU	-4.19*** (0.00)	-4.19*** (0.00)	-	-	I (0)
LAER	-6.54*** (0.00)	-3.90*** (0.00)	-	-	I (0)
LIVA	-1.87 (0.33)	-1.86 (0.34)	-4.57*** (0.00)	-4.57*** (0.00)	I (1)
LPIBH	-4.91*** (0.00)	-5.24*** (0.00)	-	-	I (0)

\*\*\*Significance at 1%

**Table 4: Results of Andrews-Zivot stationarity tests**

Variables	Level		First difference		Decision
	AZ	Break date	AZ	Break date	
LREC	-3.51 (0.38)	2005	-9.07*** (0.00)	2006	I (1)
LAEU	-49.14*** (0.00)	2007	-	-	I (0)
LAER	-5.83*** (0.00)	2012	-	-	I (0)
LIVA	-3.00 (0.68)	2013	-6.32*** (0.00)	2020	I (1)
LPIBH	-5.02*** (0.00)	2017	-	-	I (0)

\*\*\*Significance at 1%

**Table 5: Selection of the number of lags**

Lag	LogL	LR	FPE	AIC	SC	HQ
0	48.83162	NA	1.28e-08	-3.984693	-3.736729	-3.926280
1	117.7875	100.2994	2.53e-10*	-7.980679*	-6.492894	-7.630202

\*Indicates lag order selected by the criterion. LR: sequential modified 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

include a past period in order to correctly represent the dynamics of the variables and ensure an econometrically consistent specification.

Table 6 presents the results of Pesaran's cointegration test, which show a significant rejection of the null hypothesis of no cointegration at the minimum threshold of 10% for all variables in the model. That statistical outcome indicates that the REC, AEU, AER, IVA and GDPH follow a common trajectory and maintain a stable long-term relationship over the period 2000-2022. In other words, these five variables share an underlying trend that reflects the existence of a structural equilibrium towards which the system converges, confirming the relevance of ARDL modelling incorporating a long-term component.

#### 4.2.2. Model specification

Table 7 presents the results of diagnostic tests performed on the estimated model. The model satisfied the main econometric criteria, attesting to its robustness. First, the model passed the heteroscedasticity test, confirming the constancy of the variance

of the residuals. It also passed the normality test, suggesting that the errors follow a normal distribution, which is essential for the validity of statistical inferences. The serial correlation test showed no autocorrelation of the residuals, which reinforces the credibility of the estimates. In addition, the model was validated in terms of its functional form specification.

A stability test was also conducted at a 5% significance level, using the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residual squares (CUSUMQ) tests. The curves associated with these tests, shown in Figures 1 and 2, remained within the critical bands, indicating that the model parameters are stable over time.

### 4.3. Short-term Dynamics, Long-term Dynamics and Causality

#### 4.3.1 Short-term dynamics

The short-term dynamics presented in Table 8 reveal that one year ago, a 1% increase in electricity consumption in the residential

**Table 6: Cointegration test of the ARDL model**

Stat test	Value	Significance	I (0)	I (1)
F-stat	4.41	10	2.45	3.52
K	4	5	2.86	4.01

**Table 7: ARDL model robustness test**

Robustness indicators	ARDL (1,3,2,3,0)	
	Coefficient	P-value
R <sup>2</sup>	0.99	
R <sup>2</sup> Adjusted	0.98	
DW statistic	2.44	
Ramsey RESET Test	0.67	0.44
Jarque-Bera Test (Normality Test)	1.59	0.44
Breusch-Godfrey Serial Correlation LM Test	0.26	0.77
Heteroskedasticity Test (ARCH)	0.89	0.35
Heteroskedasticity Test (Breusch-Pagan-Godfrey)	0.82	0.64

**Table 8: Results of the short-term dynamics of variables**

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
D (LREC(-1))	0.978022	0.108191	9.039779	0.0001
D (LAEU)	-0.209879	0.065843	-3.187554	0.0189
D (LAER)	0.338122	0.125841	2.686903	0.0362
D (LIVA)	0.580438	0.454627	1.276734	0.2489
D (LPIBH)	-0.015183	0.169611	-0.089519	0.9316
ECT(-1)	-5.397281	2.677671	-2.015662	0.0904

\*\*\*, \*\*, \* denote significance at 1%, 5% and 10% respectively

**Table 9: Results of the long-term dynamics of variables**

Variable	Coefficient	Std. error	t-Statistic	Prob.
LAEU	-6.279359	29.83236	-0.210488	0.8403
LAER	20.34034	98.74415	0.205990	0.8436
LIVA	69.96792	361.6825	0.193451	0.8530
LPIBH	-0.690854	10.63797	-0.064942	0.9503

sector would have led to a 0.98% increase in current consumption, results observed in the work of Yawa (2023). This result suggests a certain continuity in household electricity consumption behaviour. In other words, past consumption still has a significant influence on current consumption, reflecting stability in residential usage. This can also be explained by the regularity of domestic energy needs and a relatively stable electricity supply in the areas of the country served in the short term. Table 8 also reveals that a 1% improvement in access to electricity in urban areas would lead to a 2.1% decrease in residential electricity consumption. This result, which is counterintuitive at first glance, can be interpreted as reflecting a reallocation or energy efficiency effect. In the Cameroonian context, expanding access to urban electricity could be accompanied by better structuring of usage, a shift to alternative sources (renewable energies, less energy-intensive equipment) or a transition to non-residential uses commerce, services. It may also indicate a gradual decoupling between access and intensive consumption, particularly in urban areas where rationalisation or incentive pricing policies are beginning to take effect.

On the other hand, the table also shows that access to electricity in rural areas has a positive influence on electricity consumption in the residential sector. Indeed, a 1% increase in access in rural

areas would lead to a 0.36% increase in residential electricity consumption, as observed in the studies (Lipscomb et al., 2013). This result highlights the direct impact of rural electrification on household energy demand. Extending the electricity grid to rural areas naturally stimulates residential consumption, as it enables the adoption of new uses (lighting, basic household appliances, mobile phone charging, etc.). This dynamic also reflects the role of electrification as a lever for improving living standards and energy integration, although the low elasticity of 0.36% suggests moderate growth, possibly hampered by purchasing power, service quality or the equipment available in these areas.

As for the added value of industry, although the coefficient is positive, it is not statistically significant. This means that industrial growth has no immediate observable effect on electricity use in the residential sector. This result is consistent with the work of Adom et al. (2012). This result can be explained by the structure of Cameroon's industry, which is often dominated by small, low-energy-intensive production units, or by the fact that industrial growth is reflected more in productivity gains than in increased energy consumption. Furthermore, electricity consumption in the industrial sector may be weakly linked to that of the residential sector, especially if value chains remain poorly integrated. It is also possible that the effects of industrial growth on energy demand are delayed or offset by energy efficiency or self-production policies in certain companies. Furthermore, Table 7 also shows that an increase in GDP per capita does not automatically translate into an increase in residential electricity consumption due to factors such as access, budgetary priorities, adaptation delays and malfunctions in the electricity system. The effect could become significant in the medium to long term, once these obstacles have been removed.

#### 4.3.2. Long-term dynamics

The results shown in Table 9 indicate that, in the long term, none of the explanatory variables (accessibility to electricity in urban and rural areas, industrial value added, GDP per capita) has a statistically significant effect on electricity consumption in the residential sector in Cameroon. This lack of a robust relationship can be interpreted as reflecting structural inertia in the energy system, where traditional drivers of demand do not automatically translate into actual consumption due to deep-seated constraints.

The gap between improved access to electricity and actual consumption in Cameroon's residential sector can be explained by a series of structural and economic constraints. Despite the expansion of the grid, poor service quality (frequent outages, voltage instability) limits intensive use of electricity by households, who fear damage to their equipment. Furthermore, the relatively high cost per kWh, combined with precarious incomes, encourages many households, particularly in rural and peri-urban areas, to voluntarily restrict their consumption or even turn to alternative sources (wood, coal). This phenomenon of untransformed access reflects a form of energy insecurity where the availability of electricity does not necessarily translate into significant consumption. Thus, physical access to electricity does not guarantee a corresponding increase in demand, which explains the insignificance of access variables in the long-term dynamics of the ARDL model.

Secondly, the lack of a significant effect of GDP per capita on residential electricity consumption in Cameroon can be explained by the strong socio-economic disparities that this aggregate indicator does not reflect. Indeed, GDP per capita provides a misleading average that does not take into account the actual distribution of income: GDP growth may benefit a wealthy urban minority without improving the living conditions of the majority, particularly in rural areas or in the informal economy. A large part of the population remains below the energy poverty threshold, i.e. unable to meet their basic energy needs, even if the economy is growing overall. This situation limits the income elasticity of residential electricity demand, as low-income households maintain minimal consumption, focused on lighting or small appliances. Thus, GDP growth does not automatically lead to an increase in electricity use in a context marked by unequal access to economic opportunities and household appliances.

Thirdly, the insignificance of industrial value added on electricity consumption in the residential sector can be explained by a structural decoupling between industrial growth and changes in household energy lifestyles. In Cameroon, the industrial fabric remains poorly integrated and undiversified, with a predominance of extractive or primary processing industries with low technological and economic diffusion intensity. This configuration limits the knock-on effects on stable employment, household purchasing power and access to electrical appliances. Furthermore, the link between industrialisation and energy urbanisation remains weak, as industrial expansion is not necessarily accompanied by improvements in residential infrastructure or quality urban services capable of supporting more sustained energy demand in households. Current industrialisation, which is often exogenous or export-oriented, does not therefore generate increased residential consumption, as it does not sufficiently transform domestic living conditions or access to durable goods.

Finally, the lack of a significant effect of explanatory variables on long-term residential electricity consumption reflects a structural weakness in public policies on inclusive and sustainable electrification in Cameroon. Indeed, despite the rhetoric on universal access to electricity, the strategies implemented lack coherence, territorial targeting and real support for demand. The absence of progressive or low-income-friendly tariff incentives discourages prolonged or intensive use of electricity, even after connection. Furthermore, the development of decentralised renewable energies, which could meet the needs of isolated rural and peri-urban areas, remains marginal, hampered by regulatory obstacles, insufficient funding and low involvement of local actors.

In addition, the residential sector is often relegated to second place behind industrial or institutional imperatives in national energy planning, which prevents the emergence of stable, anticipated and sustained long-term consumption. This lack of an integrated vision thus contributes to an inertia effect where physical access to energy does not translate into a real lever for development for households.

#### 4.3.3. Granger causality in the Toda-Yamamoto sense

The causality test analysis presented in Table 10 reveals a unidirectional causality from energy consumption in the residential sector to access to electricity in urban and rural areas, as well as to the value added of industry.

## 5. DISCUSSIONS

The negative short-term link between access to electricity and residential consumption, combined with the absence of a significant long-term relationship, calls into question the very nature of electrification policies. This result suggests that the expansion of the grid does not automatically translate into an increase in effective demand, particularly in the early stages of access. It highlights the persistent gap between formal access to electricity and actual household use, probably due to economic, technical or social constraints. Furthermore, the causality from consumption to access, especially in urban areas, shows that electrification policies are often reactive rather than proactive. Supply follows demand rather than anticipating it, which limits the leverage effect of electrification on development. This result therefore calls for a rethinking of approaches that focus solely on access rates as an indicator of progress, by incorporating qualitative dimensions such as continuity, cost and capacity for use.

The finding that access to electricity in rural areas has a positive short-term impact on residential consumption but no significant long-term impact opens up a debate on the sustainability of rural electrification policies. It questions the ability of the systems put in place to maintain sustained consumption. This may refer to issues of infrastructure, tariff models, maintenance, or even service continuity. This observation also raises the question of the structural limitations of rural electrification, particularly when it is not accompanied by integrated local development policies. The fact that residential consumption seems to precede the expansion of access raises the debate on investment logic: should we wait for demand to materialise before electrifying, or should we anticipate it through an energy inclusion strategy?

**Table 10: Results of the Granger causality test in the sense of Toda-Yamamoto**

Dependent variable	Explanatory variables					Decisions
	LREC	LAEU	LAER	LIVA	LPIBH	
LREC		2.57	4.11	0.18	1.04	No causality
LAEU	7.55		3.60	0.99	0.18	LREC→LAEU
LAER	14.32***	1.91		3.57	0.16	LREC→LAER
LIVA	12.00***	3.17	2.45		7.49	LREC→LIVA
LPIBH	2.42	1.43	2.15	0.52		LPIBH→LIVA
						No causality

\*\*\*, \*\*denote significance at 1% and 5% respectively

Figure 1: CUSUM

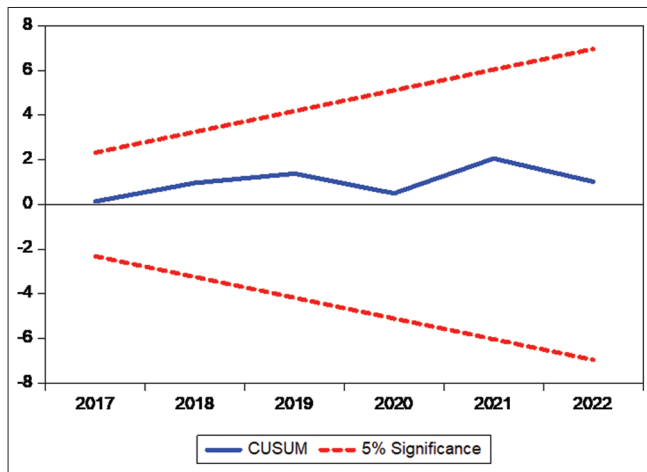
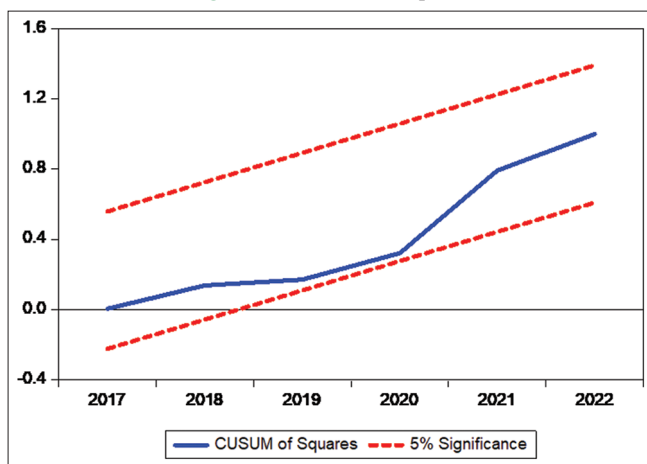


Figure 2: CUSUM of squares



Furthermore, this situation can be discussed from the perspective of territorial inequalities. If access is dictated by consumption, the poorest or least populated rural areas risk being permanently excluded from electrification efforts. This poses a challenge in terms of social justice and calls into question the priorities of certain public policies.

Finally, these results encourage reflection on the role of domestic and productive uses of electricity in rural areas. If the initial effect does not continue over time, this raises questions about the way in which populations appropriate electricity beyond their basic needs. We can then discuss the need to rethink the models of technical, economic and social support in rural electrification programmes.

The lack of a significant effect of the industry's added value on electricity consumption in the residential sector, in both the short and long term, highlights the limitations of integration between industrial dynamics and household energy needs. This result can be explained by the fact that industrialisation in Cameroon is still in its infancy, concentrated in segments that consume little energy or are isolated from urban residential centres. Industrial units are not yet sufficiently developed to have a significant knock-on effect on residential access to or use of electricity.

Furthermore, the country's economic structure, dominated by the tertiary and informal sectors, means that industrial growth has

not yet reached a level capable of directly influencing household energy demand. Residential electrification depends more on public policies, investments in distribution infrastructure, and demographic dynamics than on industrial dynamism itself. Secondly, there is a disconnect between the productive sector and households. Cameroonian industries are poorly integrated into the local economy, often concentrated in specific areas, with little direct impact on the population. Income from the industrial sector therefore does not lead to a significant increase in purchasing power or energy demand at the residential level.

Furthermore, the lack of a link with GDP per capita reflects the fact that economic growth, even when recorded, does not translate into a noticeable improvement in living conditions for the majority. A large part of the population remains excluded from stable access to electricity, especially in rural areas, and low-income levels limit the adoption of household appliances, thereby reducing energy demand. These findings reveal major challenges in terms of redistribution, the inclusiveness of industrial policies and equitable access to energy. They call for better coordination between industrial, energy and social policies to generate more harmonious and sustainable development.

## 6. CONCLUSION

This article analyses the determinants of residential electricity consumption in Cameroon over the period 2000-2022, using an ARDL model to identify long-term relationships and short-term dynamics, supplemented by a Granger causality analysis in the Toda-Yamamoto sense. The results show that, in the short term, access to electricity has a differentiated effect depending on the environment: It positively influences residential consumption in rural areas, but negatively in urban areas. On the other hand, neither industrial value added nor GDP per capita have a significant effect on residential consumption, either in the short or long term. Furthermore, the causality analysis reveals a unidirectional relationship from electricity consumption to access to electricity, in both urban and rural areas, as well as a unidirectional causality from GDP per capita to industrial value added.

Overall, these results suggest that expanding access to electricity does not automatically translate into increased residential consumption, particularly in urban areas where income constraints, energy efficiency or implicit rationing may limit the effective use of electricity. The lack of significant impact of traditional macroeconomic indicators also indicates that economic growth, taken in isolation, is not sufficient to improve household energy consumption conditions. Finally, the observed causality, from consumption to access, suggests that real demand tends to precede supply, calling into question energy planning approaches based exclusively on infrastructure expansion.

These findings have several public policy implications. First, electrification strategies must be differentiated according to the spatial context: in rural areas, extending access can stimulate productive consumption that is conducive to local development, while in urban areas, access should be accompanied by targeted policies to optimise usage and control demand. Second, the lack

of a link economic growth and residential consumption argues for better coordination between energy and social policies. Finally, energy planning would benefit from being more guided by a detailed analysis of households' real needs, in order to align investments with actual rather than potential demand.

This study focuses solely on the linear relationship between residential electricity consumption and the various explanatory variables mentioned above. Further research could explore the non-linear relationship between consumption.

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