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Research article

Post-connection electricity demand and pricing in newly electrified households: Insights from a large-scale dataset in Rwanda

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ABSTRACT

Recent electrification efforts in Africa have expanded household connections, but understanding of post-connection electricity consumption and affordability challenges remains limited. This study examines consumption patterns and price elasticity among newly connected households in Rwanda, utilizing consumption and billing data from the national utility. Using both descriptive and econometric analyses, we assess trends in electricity usage and estimate price elasticity specifically for low-consumption customers. Our findings show that newly connected households, particularly in rural areas, consume substantially less electricity than longer-standing, primarily urban customers. Furthermore, with each new year, the most recently connected use even less electricity than those connected in previous years. We observe that demand growth remains stagnant, with overall increases in demand driven by new connections rather than increased consumption among existing customers. Among low-consumption households, price is inelastic, suggesting limited capacity to stimulate demand growth solely through reduced tariffs. These results underscore the limitations of tariff policies in driving electricity consumption growth and emphasize the need for targeted interventions to enhance usage, especially for economically disadvantaged households. Our study offers insights applicable to other low-income countries undergoing similar electrification initiatives, providing valuable evidence for policymakers seeking to expand access to affordable electricity and promote sustainable demand growth.

1. Introduction

Access to electricity remains a major barrier to development in many low-income countries, particularly in Sub-Saharan Africa (Stern et al., 2019). Although governments, supported by international organizations such as the World Bank and the African Development Bank, have made substantial strides in electrification over the past decade, significant challenges persist (Shyu, 2023; Chapel, 2022). The continent is home to more than 30 countries where electrification rates remain below 50%, with approximately 570 million people still without access to electricity. In 2030, 90% of the global population without electricity access is projected to be in Sub-Saharan Africa (WHO, 2018).

Countries such as Kenya and Ghana have made notable progress in expanding electricity access, connecting millions of households to the grid. Kenya, in particular, has experienced one of the fastest electrification rates in Africa, thanks to focused policy efforts and infrastructure investments (Tesfamichael et al., 2020). However, countries like the Democratic Republic of Congo, Liberia, and South Sudan continue to struggle with low electrification rates, particularly in rural areas, where rapid population growth often outpaces efforts to expand electricity access . Rural electrification deficits persist in countries like Niger, Uganda, and Chad, while urban areas in countries such as Ethiopia and Eritrea also face growing electricity access challenges due to migration and urbanization (Falchetta et al., 2020).

Even in countries where access to electricity has expanded rapidly, many newly electrified households struggle with affordability and limited consumption. For instance, in South Africa, despite widespread electrification, household consumption remained lower than expected, often ranging between 100 and 150 kWh per month for many recently connected households due to financial constraints (Borchers et al., 2001). This reflects broader concerns about affordability, as even subsidized tariffs can be unaffordable for low-income households, leading

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them to continue relying on traditional, polluting fuels (Thom, 2000; Winkler et al., 2011).

While substantial efforts have been made to increase grid connections in Africa, many newly connected households struggle to sustain meaningful levels of electricity consumption post-connection. The high cost of electricity across the continent — despite regulated tariffs often set below cost-recovery levels — adds further complexity to the challenge of promoting sustained electricity use (Blimpo and Cosgrove-Davies, 2019). Understanding how different tariff structures influence consumption patterns is therefore essential for developing policies that not only expand access but also encourage ongoing, affordable electricity use, particularly in low-income communities.

A growing body of research has examined the impact of electrification across Africa, focusing on household energy consumption patterns and the effectiveness of various tariff structures. However, much of this research relies on indirect measures of electricity usage, such as household surveys and nighttime lights data, each with significant limitations. Surveys are often costly, infrequent, and limited to small or unrepresentative samples, while nighttime lights data provide only broad estimates of electricity access rather than specific consumption levels (Madubansi and Shackleton, 2006; Isihak et al., 2020; Chowdhury et al., 2020). These limitations highlight the need for more detailed analyses based on actual electricity consumption data to better understand post-connection behavior.

In Sub-Saharan Africa, the use of detailed electricity consumption data from grid-connected households is still limited, with most available studies focusing predominantly on South Africa. These studies have explored determinants of electricity demand and price elasticity but have not extensively covered other regions (Ye et al., 2018; Anderson, 2004; Louw et al., 2008; Jack and Smith, 2015). An exception is the work of Fobi et al. (2018), which examined consumption trends among newly electrified households in Kenya. However, a significant research gap remains to understand how tariff structures, such as increasing block tariffs (IBTs) or uniform tariffs (UTs), affect the behavior of electricity consumption, particularly in newly electrified low-income communities.

IBTs, which charge lower rates for lower consumption levels and progressively higher rates for higher consumption, are among the most common tariff schemes used across Africa (Briceño-Garmendia and Shkaratan, 2011). Utilities favor IBTs for their potential to balance cost recovery with social equity objectives. However, despite their theoretical appeal, IBTs often fail in practice to effectively target low-income households, as they may not account for situations where multiple households share a single meter, leading to regressive outcomes (Cardenas and Whittington, 2019; Briceño-Garmendia and Shkaratan, 2011). In contrast, uniform tariffs, which charge a fixed rate per kWh regardless of consumption level, are simpler to implement but may disproportionately burden low-income households. Since all customers pay the same rate, low-income households, with typically lower consumption, can struggle to afford electricity if the fixed rate is set high to ensure cost recovery for utilities (Briceño-Garmendia and Shkaratan, 2011).

Despite the prevalence of these tariff structures, there is limited empirical research on their actual impact on electricity consumption behavior, particularly among low-income households (Klug et al., 2022). Addressing this gap is crucial for designing affordable energy policies that not only ensure financial sustainability for utilities but also promote equitable and sustainable electricity usage among newly connected households.

Rwanda provides a valuable case study for examining the dynamics of post-connection electricity consumption and the role of tariff structures. Between 2011 and 2023, Rwanda's electrification rate increased from 10% to 50%, reflecting significant progress in expanding access to the grid (NISR Census, 2023). However, despite these gains, as our study shows, the country faces challenges similar to those in other low-income contexts, where newly electrified households often struggle with affordability and low consumption levels (Falchetta et al., 2020; Taneja, 2018; Boubakar et al., 2022; Mpholo et al., 2021; Okoboi and Mawejje, 2016). With a GDP per capita of just $999 as of 2024 (World Bank, 2020), Rwanda presents an ideal setting to explore how tariffs affect household electricity consumption in a resource-constrained environment.

This study addresses these gaps by conducting a comprehensive analysis of electricity consumption patterns among over 800,000 customers connected to Rwanda's grid between 2013 and 2019. Using detailed billing and consumption data from the Rwanda Energy Group (REG) contained in a transactions dataset, we examine the evolution of demand, disparities between rural and urban customers, residential and non-residential users, and the effects of tariff fluctuations on residential consumption behavior. Our findings provide valuable insights into the challenges and opportunities associated with rapid electrification in low-income settings, with broader implications for other countries undergoing similar transitions.

This paper makes several contributions to the literature: First, it expands the scope of research on post-connection electricity consumption, using the largest dataset of its kind in the region. Second, it provides estimates of price elasticity for low-consumption residential consumers in Rwanda, offering critical information for designing more effective and equitable energy pricing schemes and policy approaches that support the sustainability of energy supply systems. By situating Rwanda's experience within the broader electrification narrative in Sub-Saharan Africa, we draw lessons that extend beyond national borders and offer insights for policymakers across the continent.

2. Data

2.1. Rwanda energy group utility data

Rwanda's electrification efforts are spearheaded by the Rwanda Energy Group, also known as REG, established in 2014 (REG, 2024). REG operates through two subsidiaries: the Energy Utility Corporation Limited (EUCL) and the Energy Development Corporation Limited (EDCL). While EDCL focuses on the development of new energy generation and transmission infrastructure, EUCL is responsible for utility services and retailing electricity to end-users. This organizational division between EUCL and EDCL is designed to optimize project execution and cost-effectiveness, with EDCL primarily concentrating on development initiatives while EUCL handles grid maintenance and operation (REG, 2020).

The transaction dataset obtained from the Rwanda Energy Group (REG) provides a detailed view of electricity consumption and billing patterns for grid-connected customers over a seven-year period. Covering 361,029,383 prepaid electricity transactions made by 811,541 customers from October 2012 to April 2020, the dataset captures a wealth of information, with each transaction timestamped and linked to the corresponding customer and meter IDs, as well as the date each customer was initially connected to the grid.

However, it is important to note that this dataset does not represent the entire population of grid-connected customers in Rwanda as of 2020. According to the Ministry of Infrastructure, Rwanda had a total of 1,092,081 electricity customers as of June 2020 (MININFRA, 2020). We believe this discrepancy may be due to missing data from certain districts, as discussed later in this section. Additionally, it is likely that customers connected during 2020 are not fully captured in our dataset, further contributing to the difference in reported totals.

The Ministry of Infrastructure issues annual reports showcasing the new electricity connections made within each fiscal year. We have aligned our transaction data with the fiscal year format used by the ministry which typically begins in July and ends in June of the subsequent year. Fig. 1 illustrates that the official count of new connections closely matches the number from our dataset from 2006 to 2015. However, after 2015, a discrepancy emerges between the number of new

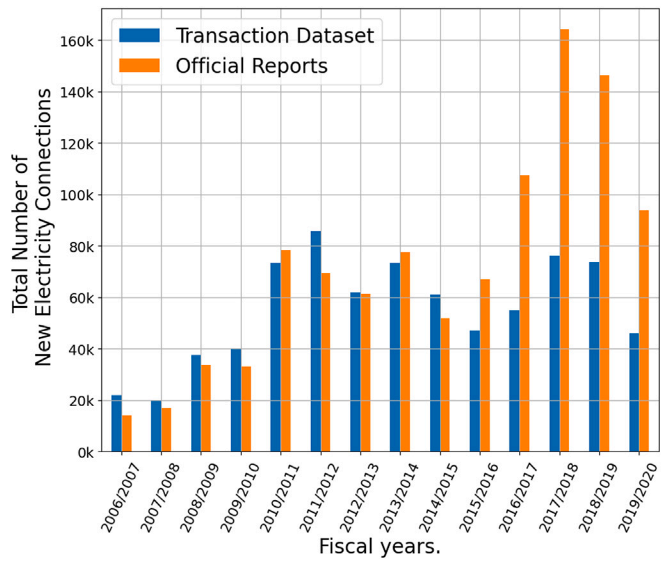


Fig. 1. Comparing annual new electricity connections by REG: Analysis from our transactions dataset vs. official reports. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

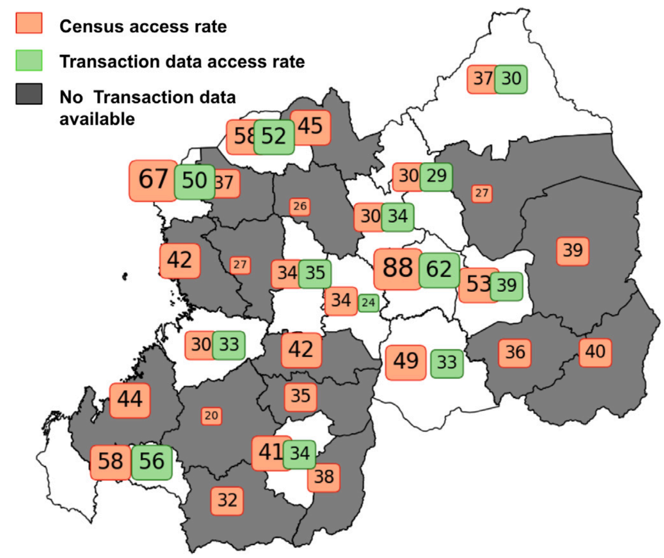


Fig. 2. Comparing grid access rates in Rwanda: Analysis from our transaction dataset versus 2022 census reports. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

connections in our transaction dataset and the numbers from official reports.Minor discrepancies from 2006 to 2015 may reflect differences in aggregation methods or potential omissions in the Ministry's data. The missing data after 2015 may result from absent records for specific districts in our dataset, as illustrated in Fig. 2.

Fig. 2 displays the grid access by district in Rwanda. To provide context on the spatial constraints of our transaction data set, we use data from the Rwanda census of 2022 (NISR Census, 2023), which outlines the number of households and the electricity access rates in each district of the country.[1] We separately calculate the access rates using our transaction data as indicated in Eq. (1). We use the total customer count extracted from our transactions dataset alongside the total household numbers derived from the 2022 census. A comparison between census-reported access rates and those derived from our transaction dataset reveals close alignment in many districts, with notable discrepancies in others. For instance, the census reports an access rate of 88% in the capital city, Kigali, compared to 62% in our transaction dataset. It is worth noting that our transaction dataset concludes in mid-2020, whereas the census was conducted at the end of 2022. Hence, disparities are expected, as our dataset does not encompass new connections made in 2021 and 2022. Furthermore, our transaction dataset contains data from only 15 of the 30 districts comprising Rwanda, as shown in Fig. 2, where districts lacking transaction data are shaded gray. Comparing the total number of customers in our dataset with official reports, we note a discrepancy of 289,540 customers. We postulate that many of these missing customers reside in the grayed-out districts lacking transaction data. For the districts included in our dataset, however, we believe our data provides a complete representation of all customers and their transactions at the time it was compiled. This makes our dataset one of the most comprehensive to date for studying electricity consumption patterns in a low-income country.

$$\text{Access Rate} = \frac{\text{Customers in District}}{\text{Total Households in District}} \tag{1}$$

[1] We consolidate the three districts comprising the capital, Kigali, into a single district. This aggregation is to maintain consistency with our transactions dataset, where all districts forming the capital Kigali are merged into one. We maintain this format to facilitate a direct comparison with the 2022 census results.

Our transaction dataset includes detailed information on the amount of electricity purchased and the corresponding payment made by each customer. While Value Added Tax (VAT) is applied to electricity purchases, it remained consistently fixed at 18% during our analysis period (2013–2020). Therefore, we exclude it from our analysis (PWC, 2024; MINECOFIN, 2024).

Throughout the dataset period, there were occasional revisions in how customers were categorized as residential or non-residential. For this study, we adhere to the final categorization as of 2020. Based on this categorization, 88% of customers are classified as residential, with the remaining 12% categorized as non-residential. Non-residential entities include small commercial establishments, telecommunication installations, hotels, and health facilities. Large industrial customers are not included in the dataset.

2.2. EICV survey data

Our secondary data source is the Integrated Household Living Conditions Survey (EICV), a nationwide cross-sectional survey initiated in 2000 and conducted periodically by the National Institute of Statistics of Rwanda (NISR). The EICV is designed to assess the living conditions of households in Rwanda, providing detailed data on various socioeconomic variables such as income, consumption, education, health, housing, and access to utilities such as electricity and water.

Each round of the survey employs a two-stage stratified sampling design to ensure national representativeness. In the first stage, the enumeration areas are selected with a probability proportional to the size, followed by a systematic selection of households within these areas in the second stage. The sample sizes across different rounds vary, generally encompassing between 7,000 and 14,000 households per round, ensuring comprehensive coverage across Rwanda's provinces and both urban and rural areas (NISR EICV, 2021).

For this study, we use data from the 2013/2014 and 2016/2017 surveys. The 2013/2014 survey covered approximately 14,419 households, while the 2016/2017 survey expanded to include 14,580 households. However, due to the inability to match individual household survey data with electricity consumption records, we calculate district-level averages for each sociodemographic characteristic, covering 15 districts, corresponding to the districts in our consumption dataset.

The aggregation of variables at the district level is a well-established practice in the literature, particularly when disaggregated household

Table 1
Descriptive statistics of key survey variables by district.

Variable	Mean	Standard Deviation	Minimum	Maximum
Average annual household income (rwf)	1,320,000	882,000	596,000	4,820,000
Average number of household rooms	3.6	0.3	3.0	4.2
Average number of household members	4.5	0.2	3.9	5.0
Average age of household head	45.1	2.4	39.1	48.6

data are not available or are costly to obtain (Chovar Vera et al., 2024). Although disaggregated data are preferable for detailed analysis, the combination of district-level sociodemographic information with electricity consumption data allows for a larger and more robust panel, which strengthens the estimation process in our study.

Table 1 presents key statistics from the EICV survey, including household income, number of household members, age of household head, and number of household rooms. These statistics provide a contextual understanding of the socioeconomic conditions in each district, allowing us to control for these conditions in our regression analysis.

In Appendix A.1, we compare essential household characteristics — such as room count, household expenditure, number of household members, and household head age — between districts included in the REG transaction dataset (shown in white in Fig. 2) and those not covered (shown in gray in Fig. 2). The distributions of these features are similar across the two sets of districts, suggesting that our dataset is reasonably representative of the broader population.

This section outlines the structure and limitations of the data used in this study. While the REG transaction dataset provides a detailed view of electricity consumption patterns among a substantial portion of Rwanda's grid-connected households, it does not include some districts or the most recent connections. Nevertheless, when combined with district-level socioeconomic data from the EICV survey, our dataset offers valuable insights into consumption trends and the impact of tariff structures on electricity consumption across Rwanda. The following sections will analyze these relationships in greater detail.

3. Methodology

3.1. From pre-paid purchases to monthly consumption

Prepaid meters have emerged as the predominant method for managing electricity consumption in sub-Saharan Africa (Jack and Smith, 2020). Facilitated by prepaid meters, prepaid transactions entail a payment method where customers purchase credit or units of service in advance, which are then gradually depleted as they utilize the service. This system is particularly favored in regions with unreliable or irregular service provision, as it mitigates the risk of non-payment and enables utilities to manage demand more effectively.

However, one drawback of the prepayment system is its divergence from the postpaid system, where customers typically make payments at regular intervals, often at the end of each month. Prepaid customers exhibit less regular purchase patterns, as depicted in Fig. 3, showcasing the dispersed nature of the total number of purchases customers make on an annual basis. For example, in 2016, customers made a varying number of prepaid purchases, ranging from a single purchase to as many as 130 purchases. To provide context, making 130 purchases would equate to purchasing electricity approximately every three days.

Our entire transaction dataset comprises prepaid customers. Less than 0.3% of customers on the Rwanda National Grid use postpaid meters, underscoring the dominance of the prepaid system in Rwanda and the representativeness of our data (REG, 2021).

To ensure a consistent comparison of consumption patterns over time, we employ a pre-processing strategy similar to Jack and Smith (2020). This involves distributing customer consumption using transaction dates to construct average daily kWh consumption, assuming a constant rate of consumption per day between transactions. Unlike Jack and Smith (2020), we use the median purchase frequency for each

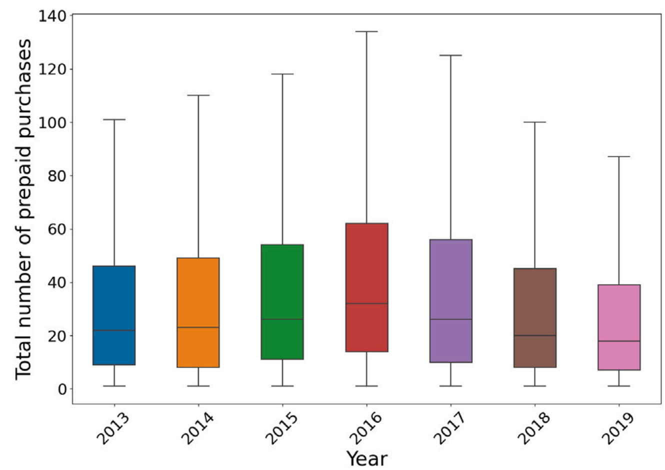


Fig. 3. Distribution showing the total number of prepaid electricity purchases customers made as computed from the transactions dataset.

customer in scenarios where customers have excessively long periods without purchases. This adjustment process helps to avoid underestimating monthly electricity consumption during periods with sparse transactions. By smoothing consumption across both short and long intervals between purchases, the method provides an estimate of typical monthly usage.

Our process unfolds as follows: for any two sequentially occurring purchase periods, if the time delta between the two periods was less than the median purchase frequency, the consumption was spread evenly between both periods on a daily basis. If the time delta between the two periods exceeded the median purchase frequency, the purchased units were spread over the median purchase frequency of the customer to prevent instances of very low consumption. Subsequently, the daily consumption is aggregated to monthly consumption. This process assumes that customers do not accumulate electricity credit on their meter. The transformation process effectively converts stochastic electricity purchases to monthly electricity consumption, facilitating further analysis. Importantly, the transformation preserves the customer consumption trends, as evidenced by Fig. 4.

3.2. Empirical strategy

3.2.1. Temporal segmentation

To gain insight into the evolution of residential electricity demand over time, we employ a data reshaping methodology similar to that used in Fobi et al. (2018). This method leverages the duration of each customer's grid connection to explore the typical alterations in electricity consumption patterns as the duration of grid connection increases. Using this data reshaping technique, we aim to provide a more comprehensive understanding of the underlying dynamics that govern residential electricity demand as it evolves over time.

3.2.2. Customer segmentation

Over the past decade, Rwanda has implemented several tariff adjustments, significantly impacting electricity pricing for residential consumers. Table 2 provides an overview of the tariff structures from 2006 to 2018. For this study, we focus on tariff changes in 2015 and

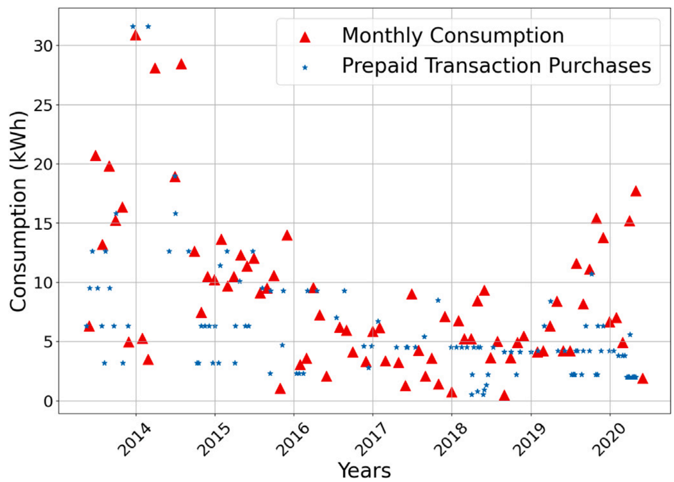


Fig. 4. Illustrative consumption history for a single customer selected at random. The blue dots show the customer's prepaid purchases, note that these are not at regular intervals and sometimes several purchases could be made within a month. The red triangles show the same customer's consumption aggregated for each month.

Table 2
Rwanda residential tariff structure (2006–2018).

Year	Tariff type	Consumption block (kWh)	Tariff rate (rwf per kWh)
2006 2012 2015	Uniform Tariff (UT)	ALL	112 134 182
2017	Increasing Block Tariff (IBT)	0–15 15–50 50	89 182 189
2018	Increasing Block Tariff (IBT)	0–15 15–50 50	89 182 210

Note: This study focuses on the tariff changes implemented in 2015 and 2017.

2017. In 2015, tariffs increased by 35%, reaching 182 RWF per kWh, driven by rising generation costs due to reliance on thermal energy (The NewTimes, 2015b; RURA, 2018).

In 2017, Rwanda introduced an increasing block tariff (IBT) scheme aimed at applying higher rates to high-consumption households while offering subsidized "lifeline" rates to low-consumption households. The IBT divides consumption into blocks with progressively higher rates as usage increases: the first 15 kWh are billed at the lowest rate, the next 35 kWh (from 15 to 50 kWh) at a higher rate, and any consumption above 50 kWh is subject to the highest rate. This tariff is applied progressively, meaning that all customers pay the lowest rate for the first 15 kWh, the middle rate for consumption between 15 and 50 kWh, and the highest rate only for consumption above 50 kWh. The theoretical objective of introducing the IBT was to achieve cost recovery while maintaining affordability for low-income consumers (IDA, 2018; The NewTimes, 2015a). However, as discussed in the introduction, these types of tariffs often prove to be regressive in practice, failing to effectively target low-income households (Cardenas and Whittington, 2019).

For our analysis, we segment customers into two categories: **low-demand** and **high-demand**, based on their historical consumption levels. A customer is classified as low-demand if their monthly consumption consistently remained below the lifeline level of 15 kWh for the 12 months preceding a tariff change; in other words, their monthly usage did not exceed 15 kWh during this period. All other customers are categorized as high-demand. Additionally, customers with incomplete consumption records (i.e., missing data within the 12-month period) are excluded from the analysis. This segmentation allows us to examine the effects of tariff changes on electricity consumption behaviors across both low- and high-demand customers.

3.2.3. Estimating price elasticity of electricity demand

Our empirical approach employs a log–log functional form to estimate the price elasticity of electricity demand—a widely used method in the literature to analyze price responsiveness in energy consumption. This specification is particularly advantageous as it simplifies the interpretation of coefficients: the estimated coefficient on the price variable directly represents the price elasticity of demand, indicating the percentage change in electricity consumption associated with a 1% change in price. This form also facilitates a straightforward comparison of our results with existing studies on electricity price elasticity.

The primary outcome of interest is household electricity consumption, measured in kilowatt-hours (kWh). Our objective is to evaluate how changes in the tariff structure have influenced household consumption behavior.

Estimating demand under block rate pricing schemes presents a key challenge due to the endogeneity of the electricity price. In block tariff systems, price and quantity are jointly determined because households can influence their marginal price by adjusting their consumption. This interdependence creates a correlation between the price variable and the error term, leading to biased estimates if ordinary least squares (OLS) regression is used (Deller et al., 1986; Hassen et al., 2022). Additionally, demand for electricity fluctuates due to non-price factors, further complicating estimation.

In our study, we focus our price elasticity analysis on customers whose monthly consumption consistently remains below 15 kWh across the entire dataset. This approach is motivated by two key factors. First, low-consumption customers represent a large portion of our dataset as we show later in Fig. 5(a), making them of particular interest to both the utility and the broader research community. Second, because these customers do not encounter tiered pricing, their electricity prices can be treated as exogenous to their consumption levels. This exogeneity allows us to obtain more precise elasticity estimates without relying on instrumental variables, which can be challenging to identify and apply in data-limited contexts like Rwanda.

Following Chovar Vera et al. (2024), we estimate the demand model using a OLS fixed-effects approach to examine how low-consumption households respond to electricity price changes. The fixed effects model accounts for time-invariant unobserved household characteristics that could affect consumption. We implement our regression analysis using the plm library in R (Yves Croissant, 2024).

The demand equation is specified as follows:

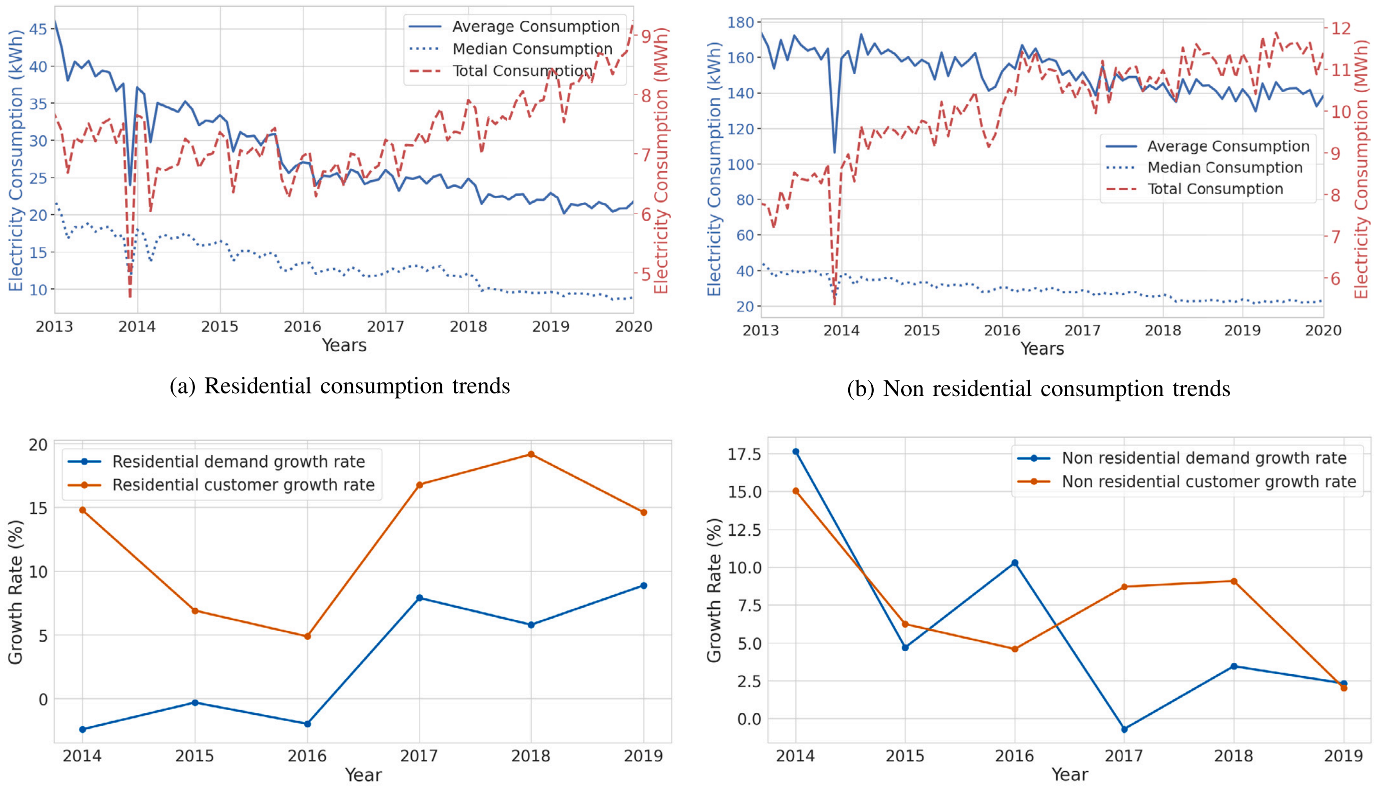
$$\ln(x_{it}) = \alpha \ln(p_{it}) + \delta Z_{it} + \gamma_i + \epsilon_i \tag{2}$$

In Eq. (2), $\ln(x_{it})$ is the natural logarithm of electricity consumption for household i in month t, while $\ln(p_{it})$ is the natural logarithm of the average electricity price faced by household i in month t. The coefficient α represents the price elasticity of demand, the central parameter of interest.

The matrix Z_{it} includes household-specific control variables, such as the number of household members, household expenditure, the number of rooms in the household, the age of the household head and the number of monthly prepaid electricity purchases. The term γ_i captures household fixed effects, absorbing time-invariant unobserved household characteristics, while ϵ_i represents unobserved factors not explained by the model.

For our analysis, we use the average price as the price variable. Since we focus on customers with monthly consumption below 15 kWh — who are not subject to tiered pricing — the average and marginal prices for these households are effectively the same[2]

[2] It is worth noting, however, that Ito (2014) suggests that, under nonlinear tariffs, consumers generally respond more to average prices than to marginal prices. This preference may be due to cognitive difficulties in understanding complex pricing structures, limited access to real-time consumption information, and uncertainty about future usage.



(a) Residential consumption trends

(b) Non residential consumption trends

(c) Aggregate year-on-year growth rates residential customers

(d) Aggregate year-on-year growth rates non-residential customers

Fig. 5. Residential and non-residential electricity consumption patterns and growth rates from 2013 to 2020. Subplots (a) and (b) display trends in average, median, and total consumption for residential and non-residential customers, respectively. Subplots (c) and (d) illustrate the aggregate year-on-year growth rates in electricity demand and customer base for both residential and non-residential customer groups. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

By estimating the price elasticity for low-consumption customers, we aim to provide policymakers with insights into the effectiveness of tariff adjustments in achieving objectives like encouraging electricity usage and ensuring affordability.

4. Results

4.1. Consumption trends: Residential vs non residential customers

This section provides a descriptive analysis of electricity consumption patterns for both residential and non-residential customers over the period from 2013 to 2020.

Fig. 5 shows electricity consumption trends and year-on-year growth rates for both customer segments. Subplots 5(a) and 5(b) present the average, median, and total electricity consumption for residential and non-residential customers, respectively.

For residential customers, there is a steady decline in electricity consumption from 2013 to around 2017. Both average and median consumption show consistent decreases over this period, while total consumption is more stable and increases after 2017. This divergence between total consumption and individual (average/median) consumption suggests that more customers are being connected to the grid, but their per-household consumption is lower, bringing down the overall individual consumption. This reflects the integration of lower-consuming households over time.

Non-residential consumption exhibits more variability. Average consumption fluctuates significantly, while total consumption increases sharply between 2013 and 2016, followed by more moderate growth. Median consumption remains notably lower than average consumption, indicating high disparity in consumption levels among non-residential customers, with a small number of high consumers dominating the data.

Despite the growth in nation-wide annual consumption, Fig. 5 illustrates a consistent decline in average monthly electricity consumption for both residential and non-residential customers. In January 2013, the average residential customer consumed about 45 kWh, while the average non-residential customer consumed about 170 kWh of electricity. By December 2019, the average residential customer's consumption had decreased by more than half to about 22 kWh, and the average non-residential customer's consumption had reduced by about 20% to 137 kWh. This highlights the fact that more lower consuming customers are getting connected to the grid.

Subplots 5(c) and 5(d) display the aggregate year-on-year growth rates of electricity demand and the customer base for both residential and non-residential customers.

The residential demand growth rate shows significant variability, with notable dips in 2014 and 2016, followed by a sharp increase in 2017. Interestingly, 2017 also sees a significant spike in the customer growth rate, reaching 16.8%, compared to a demand growth rate of 7.9% the same year. This mismatch indicates that while many new customers were added, their consumption remained relatively low, contributing to the overall decrease in average consumption.

For non-residential customers, both the demand growth rate and customer base growth rate show a declining trend over time, with the demand growth rate exhibiting more volatility. This suggests that while the nonresidential customer base continues to grow, the rate of increase in electricity demand is slowing.

Due to the prepaid nature of transactions, we can investigate the frequency with which customers make purchases. Our dataset provides insights into the time intervals between purchases and the quantity of electricity acquired in each transaction. In Kigali, residential and non-residential customers typically make purchases every 16 and 13 days on average, respectively. The average purchase amount for residential customers stands at 13 kWh, while non-residential customers acquire an average of 47 kWh per transaction.

In contrast, customers outside Kigali show a distinct trend. Here, residential customers typically make purchases every 37 days on average, while non residential customers do so every 20 days. Additionally, the average amount of electricity acquired per transaction is 7.2 kWh for residential customers and 21.2 kWh for non residential customers.

Our dataset reveals that urban residential customers purchase electricity units for their accounts with a frequency 60% lower than their rural counterparts, and they consume 50% more electricity with each purchase. This combination shows that, on average, a residential customer outside Kigali consumes 71 kWh annually, compared to the 297 kWh consumed by an average residential customer in Kigali.

According to a report by USAID Power Africa Market Assessment, rural electricity consumption in Rwanda in 2019 was 9.9 kWh per month, compared to 29.2 kWh per month in urban areas (USAID, 2019). These findings echo our observations from the transaction dataset, highlighting the significant disparity in electricity consumption between urban and rural areas in the country. The pattern of small, frequent transactions is indicative of liquidity constraints and difficulties in income smoothing, suggesting that the pay-as-you-go model of prepaid meters is preferable for low-income households compared to a monthly billing cycle. A study by Jack and Smith (2015) on electricity purchasing patterns in South Africa through prepayment meters found that households in the bottom income quintile tended to buy electricity three times as often, but in amounts that are only one-fifth of those purchased by households in the top quintile.

The GDP per capita in Kigali in 2017 was estimated at 2,865 USD, compared with 512 USD for non-Kigali districts (odi, 2020). When juxtaposing the GDP per capita figures in Kigali and outside Kigali with electricity consumption patterns, striking parallels emerge. The electricity consumption of Kigali residents is approximately four times higher than that of residents outside Kigali, mirroring the disparity in GDP per capita, where the GDP per capita in Kigali is about five times higher than that of residents outside of Kigali.

These pronounced correlations between GDP per capita and electricity consumption provide insights into how affordability significantly limits rural residents' access to and utilization of electricity as an energy source.

In the following sections, we focus specifically on residential customers.

4.2. Consumption trends: Grid connection year

As shown in Section 2.1, the number of new customer connections in our transaction dataset is notably lower between 2016 and 2020 than the counts reported by official government sources. This disparity raises the possibility of bias within our dataset, wherein customers may be skewed, for example, towards wealthier or poorer segments of the country. This caveat is an important lens through which to interpret our findings in this section.

Fig. 6 offers a detailed analysis of electricity consumption patterns, categorized by the year of grid connection. The subplot 6(a) tracks the average monthly electricity consumption (in kWh) for residential customers across different connection years, providing insights into how consumption evolves as customers remain connected to the grid over time. Subplot 6(b) shows the corresponding monthly customers for each connection year.

In subplot 6(a), we observe that residential customers connected in earlier years (2013–2015) tend to stabilize their consumption after the initial few months, maintaining relatively higher levels compared to those connected more recently. For example, residential customers connected in 2013 exhibit steady consumption levels around 18–20 kWh after approximately 20 months, while those connected in 2017 and later years tend to consume less, averaging between 8–14 kWh. This pattern suggests that more recent customers may have lower electricity needs or face challenges that limit their consumption such as financial constraints.

Subplot 6(b) illustrates the number of active residential customers each month, based on their year of connection. The data shows that more recent connection years (post-2016) have a larger number of monthly customers compared to earlier years, reflecting the success of recent electrification efforts in expanding access to the grid.

A notable outlier in both plots is the cohort of customers connected in 2016. In subplot 6(a), this group exhibits the highest levels of average monthly consumption, while in subplot 6(b), they represent the smallest number of active customers. This anomaly can be partially explained by government policies in 2016, which specifically targeted high-consumption users as part of a revised electrification strategy (Mininfra, 2016). However, without more granular household data, this hypothesis remains speculative.

These consumption patterns align with similar observations made by Fobi et al. (2018) and Muhwezi et al. (2021) among grid-connected residential and small commercial electricity consumers in Kenya. However, consumption levels in Rwanda are lower, which suggests that energy providers may need to adopt significantly different electrification strategies to meet the unique needs of these customer groups.

Another key observation is the slight increase in average consumption among customers connected in more recent years, particularly in 2017, while consumption among earlier connection years remains relatively stable or slightly declines as they "mature" on the grid. This suggests that nationwide growth in electricity demand is largely driven by the addition of new customers rather than an increase in consumption by existing ones. For utility providers, this underscores the need to cater to an expanding customer base with static or modest consumption growth. Such insights are crucial for accurately forecasting demand and planning infrastructure expansions.

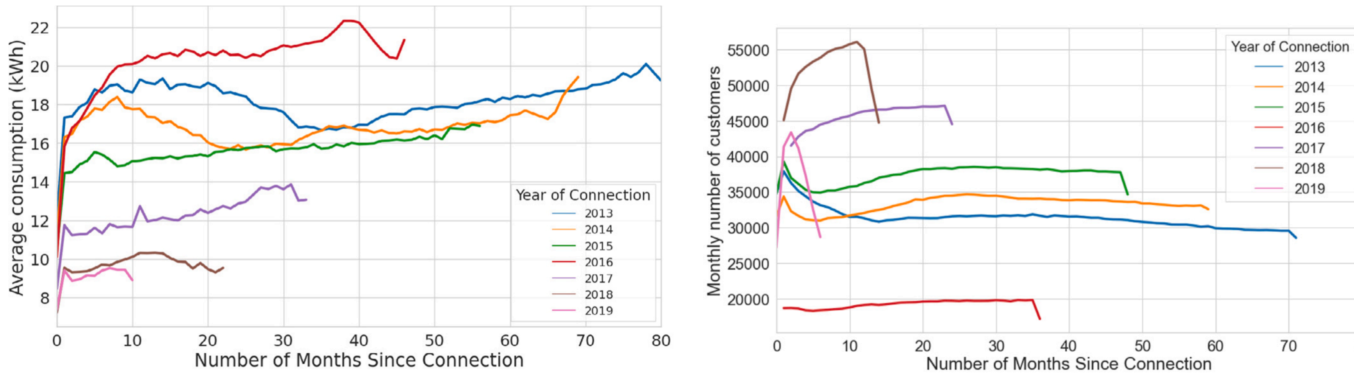
Additionally, there is a noticeable decline in consumption for customers connected in 2013 and 2014, occurring after approximately 20 and 10 months, respectively. This drop may be attributed to the 2015 tariff increase, which likely impacted these earlier customer groups who had already reached a "mature" stage of consumption. In contrast, customers who connected after the 2015 tariff hike exhibit more stable consumption patterns, having entered the grid under the higher tariff regime.

In Appendix B, Table B.1 shows a relationship between months since grid connection and monthly consumption. On average, we observe a slight decline in consumption over time, consistent with the trends seen in some connection cohorts in Fig. 6(a). We hypothesize that this decline may be partially due to improved appliance efficiency, such as the replacement of incandescent bulbs with more efficient alternatives.

Overall, these plots illustrate the evolving nature of electricity consumption in Rwanda. The differences in consumption trends based on connection year emphasize the importance of designing policies and interventions that address the distinct needs and behaviors of customers according to their connection history. Tailored strategies will be essential for managing future demand and ensuring sustainable grid expansion.

4.3. Consumption trends: Tariff impacts

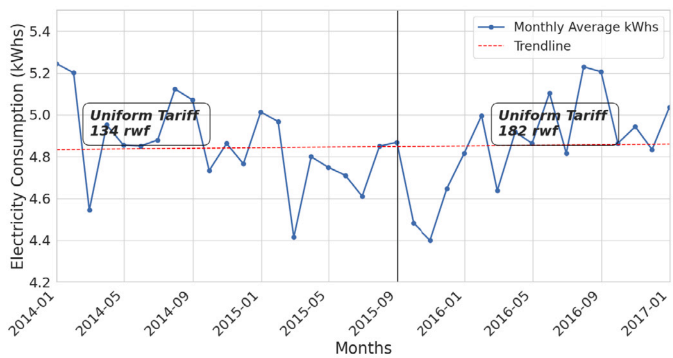
In this section, we examine the impact of tariff changes on electricity consumption. As indicated in Table 2, Rwandan customers experienced three tariff adjustments between 2013 and 2020. We primarily focus on the tariff adjustments in 2015 and 2017. To analyze the effects of these tariff changes, we categorize customers into low- and high-demand groups, as outlined in Section 3.2.2. The graphs in Fig. 7 provide an examination of the electricity consumption trends for both customer segments in response to the tariff adjustments. The analysis



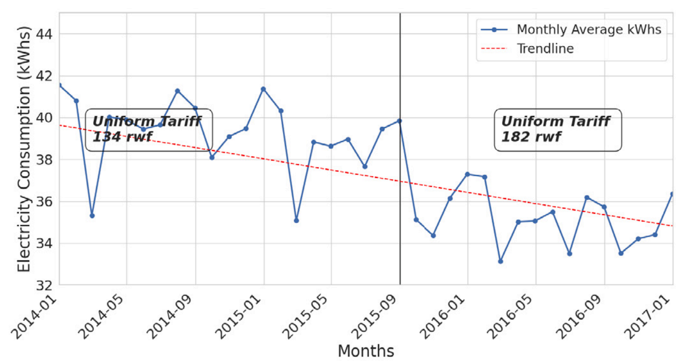
(a) Average electricity consumption (kWh) over time for residential customers grouped by their year of grid connection

(b) Monthly number of residential customers over time, categorized by their year of grid connection

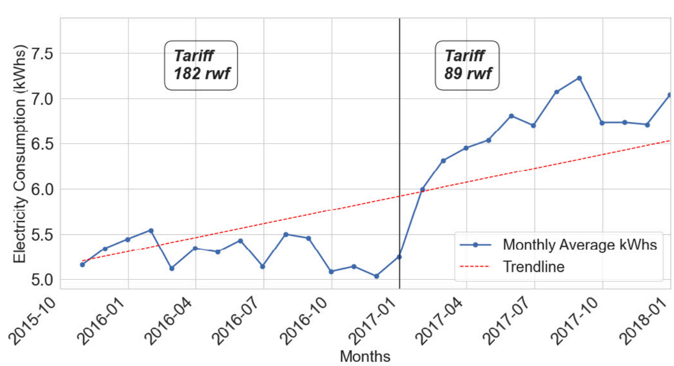
Fig. 6. Comparison of average electricity consumption and customer numbers over time for residential customers, segmented by the year of grid connection. The left plot shows the trend in average consumption (kWh) as customers spend more time connected to the grid, while the right plot illustrates the change in the number of active monthly customers for each grid connection year. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



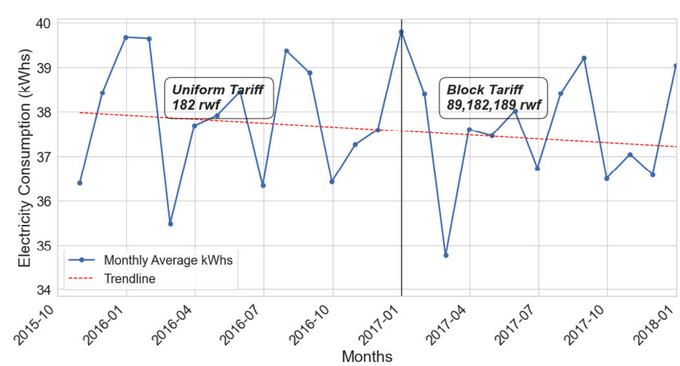
(a) Average monthly consumption for 30,004 low-demand customers highlighting the impact of the 2015 Tariff change



(b) Average monthly consumption for 147,900 high-demand customers highlighting the impact of the 2015 Tariff change



(c) Average monthly consumption for 60,848 low-demand customers highlighting the impact of the 2017 Tariff change



(d) Average monthly consumption for 146,021 high-demand customers highlighting the impact of the 2017 Tariff change

Fig. 7. Monthly average electricity consumption trends for low- and high-demand customers from 2014 to 2018, demonstrating the impact of the 2015 and 2017 tariff changes.

focuses on customers with consistent monthly consumption, 12 months before and 12 months after each tariff change. Customers with gaps in their consumption data were excluded from the analysis, as described in Section 3.2.2.

To isolate the effect of tariff changes from shifts in customer composition, we restrict the analysis to customers who had been connected to the grid for at least two years before each tariff adjustment. Specifically, for the 2015 tariff change, we include only customers connected by the end of 2013, and for the 2017 change, only those connected by the end of 2015. While this approach limits our sample size, it reduces potential for confounding the tariff impacts by recently connected customers, who, as established, tend to have lower consumption levels.

The first set of graphs (7(a) and 7(b)) covers the period from January 2014 to January 2017, focusing on the effects of the 2015 uniform tariff hike. For low-demand customers (subplot 7(a)), there appears to be no change in monthly consumption following the increase in the tariff. High-demand customers (subplot 7(b)) exhibit a slight continuous decline in consumption, which appears to exacerbate following the tariff hike, indicating a stronger behavioral adjustment to increased costs.

The next set of graphs (7(c) and 7(d)) extend the analysis to January 2018, capturing the effects of the 2017 block tariff, which introduced tiered pricing (see Table 2). For low-demand customers (subplot 7(c)), consumption shows an overall upward trend after introducing the block tariff, possibly reflecting an adaptation to the lower rate for the first consumption block. This may have incentivized higher usage within the low-consumption group. Although the tariff rate for this group was nearly halved, the corresponding increase in consumption is modest.

In contrast, high-demand customers (subplot 7(d)) show more volatility, with periods of increasing and decreasing consumption. This suggests a more complex response to the block tariff structure, where different segments of high-demand customers may be adjusting their behavior in varying ways depending on their specific consumption needs and sensitivity to the tiered pricing.

Appendix B provides regression results (Table B.1) to quantify the impact of these tariff changes on consumption as observed in Fig. 7. Our findings show that, in response to the 2015 uniform tariff hike, very high-consumption customers (average monthly consumption above 50 kWh) reduced their usage while low-consumption customers (average below 15 kWh) had a muted response, indicating a greater sensitivity to price increases among very high-demand users. Following the 2017 block tariff implementation, very high demand customers exhibited reduced consumption, while those consuming below 15 kWh per month showed a modest increase in usage.

This segmented analysis highlights the diverse behavioral responses within the customer demand groups and underscores the importance of accounting for customer heterogeneity when evaluating the impact of tariff structures. The varying degrees of price sensitivity observed in these different customer segments suggest that a one-size-fits-all approach to tariff design may not be effective. Instead, these insights point to the need for more targeted and nuanced tariff policies that consider the differing levels of price responsiveness across customer groups.

In the following section, we focus on the short-term impact of price changes on consumption. However, it is important to recognize that factors beyond price — such as household income, energy efficiency improvements, and access to alternative energy sources — can also influence the consumption trends observed. Due to limitations in our dataset, we are unable to fully capture the impact of these additional factors.

4.4. Price elasticity

In this section, we examine customers' sensitivity to price changes. Our objective is to evaluate how changes in tariff structures have influenced consumption, particularly among low-consumption customers, whom we define as those using less than 15 kWh per month.

Table 3 presents the fixed effects regression results for low-consumption customers. The dependent variable in both models is the natural logarithm of electricity consumption, with controls for monthly prepaid electricity purchases, months since household connection, monthly crude oil average price, household fixed effects, and aggregate socioeconomic controls from the EICV survey at the district level.

In both Panel A and Panel B, the coefficient on Log Average Price is negative and statistically significant at the 1% level, with values of −0.312 in Panel A and −0.319 in Panel B. This indicates that an increase in the average price of electricity is associated with a decrease in monthly consumption. Specifically, a 1% increase in the average price of electricity corresponds to an approximate 0.312% reduction in monthly consumption in Panel A, and a slightly larger reduction of 0.319% in Panel B.

The coefficient for Monthly Prepaid Purchase Count is positive and significant, suggesting that households with more frequent prepaid electricity purchases tend to consume more electricity on average. The variable Months since Connection is negative and significant in both models, indicating, on average, a gradual slight decline in household electricity consumption over time.

Panel B includes aggregate household characteristics at the district level from the EICV surveys, enhancing the robustness of our results and lending greater confidence to our price elasticity estimates. Both models incorporate household fixed effects to control for unobserved, time-invariant household characteristics.

In summary, our findings confirm that price elasticity is negative and inelastic in both models, indicating that electricity demand decreases as prices rise, consistent with the behavior of a normal good.

5. Discussion

5.1. Consumption trends

Electricity consumption trends in Rwanda, as observed in our findings, align with broader regional patterns. Studies such as Blimpo and Cosgrove-Davies (2019) highlight low average consumption across Sub-Saharan Africa, with figures as low as 483 kWh per year in 2014. National utility data from Kenya, Togo, Lesotho and Uganda similarly show overall low consumption and declining consumption over time, particularly among newly connected and rural customers (Taneja, 2018; Boubakar et al., 2022; Mpholo et al., 2021; Okoboi and Mawejje, 2016). In Rwanda, Lenz et al. (2017) reported a median consumption of just 6 kWh per month, which is enough to power basic appliances but falls short of supporting higher electricity demand. Peters and Sievert (2016) echo these findings in a Rwanda study. Our results align with these observations, showing that most customers exhibit low consumption, with only a small group of high-usage customers driving up the average. This imbalance likely stems from the expansion of the electricity grid, as most new connections serve low-demand households, thus lowering the overall consumption per customer.

The progressive decrease in average consumption each year as new customers are added is a noteworthy trend in Rwanda's electrification efforts. The introduction of a flexible connection fee payment scheme in 2017 — previously a one-time upfront charge (REG, 2022; ESRF, 2019) — likely encouraged more connections but also led to higher effective costs for newly connected households, which may explain the lower consumption among these groups. Income remains a critical factor in shaping electricity demand, as lower-income, rural households generally consume less electricity. Furthermore, the implementation of a "lifeline" tariff has had a limited impact on increasing consumption among low-tier users, who might continue to prioritize essential needs. Energy efficiency initiatives, such as replacing incandescent bulbs with more efficient alternatives, may also contribute to the observed plateau in consumption among earlier adopters (UNCC, 2014; Colenbrander et al., 2019). These findings suggest that policymakers will need to account for the low consumption levels among new, lower-income customers while ensuring that electricity remains affordable for customers and financially viable for utilities.

5.2. Price elasticity

As discussed in Section 1, there are few studies that estimate residential price elasticity in African contexts, with reported values ranging from −0.04 to −0.89 (Klug et al., 2022). Given the limited number of studies and the diversity of African countries, this wide variation in elasticity estimates is not unexpected. For comparison, we draw on two key studies that estimate price elasticity in Ethiopia: Iimi et al. (2019), which reports an elasticity of −0.29, and Hassen et al. (2022), which estimates elasticity at −0.38. These values are closely aligned with our own estimates in this study.

It is important to emphasize, however, that both Ethiopian studies rely on relatively small and geographically limited sample sets, which may affect the generalizability of their findings. Similarly, our estimates have limitations; they are specific to low-consumption customers,

Table 3
Price elasticity regression results.

	Dependent variable:	
	Log monthly consumption (kWhs)	
	Panel A (1)	Panel B (2)
Log Average Price	−0.312*** (0.002)	−0.319*** (0.003)
Monthly Prepaid Purchase Count	0.196*** (0.0005)	0.196*** (0.0005)
Months since connection	−0.004*** (0.00003)	−0.004*** (0.00004)
Crude Oil Average Price	Yes	Yes
EICV Controls		
Log Expenditure	No	Yes
Household Members	No	Yes
Room Count	No	Yes
Average HH Age	No	Yes
HH Fixed Effects	Yes	Yes
Observations	1,851,063	1,851,063
R^2	0.089	0.089
Adjusted R^2	0.074	0.075
F Statistic	59,168.230*** (df = 3; 1821718)	22,308.890*** (df = 8; 1821713)

Note: Panel A excludes socio-demographic controls, while Panel B includes them. *p < 0.1; **p < 0.05; ***p < 0.01.

defined as those consuming less than 15 kWh per month, and do not account for high-consumption households. Therefore, while our findings are comparable to those from Ethiopia, they are specific to a particular segment of the customer base and may not fully capture price elasticity across the broader population.

6. Conclusion and policy implications

6.1. Policy implications

The analysis of electricity consumption patterns among newly connected households in Rwanda offers key insights that can guide future energy policies. With consumption plateauing among early adopters and more recent connections exhibiting lower usage, policymakers should prioritize initiatives that encourage higher-intensity electricity use in households. For example, promoting the adoption of electric cooking technologies could increase consumption and ensure that households fully benefit from electrification.

Our findings emphasize the need for flexible, context-specific tariff structures that account for varying consumption patterns, income levels and responses to tariff changes. Multilateral agencies like the World Bank and African Development Bank should support utilities and regulators in creating tariffs that balance affordability with cost recovery, reducing subsidy leakage, and improving revenue collection. For newly connected lower-income households, tariffs must encourage electricity use without undermining utilities' financial sustainability. Targeted subsidies or adjusted lifeline tariffs can help achieve this balance.

Improving data infrastructure and supporting research on electricity consumption behaviors and tariff impacts is another critical area for policy development. Enhancing the technical capacity of utility companies, particularly in data collection and analysis, would provide invaluable insights for crafting effective policies. Comprehensive, high-quality datasets are essential for understanding consumption patterns and tailoring interventions to specific regional and national contexts.

Additionally, understanding the impact of off-grid solar adoption on household electricity consumption is increasingly important as solar energy systems become more prevalent across Africa. Although our study does not include data on solar adoption, future research should examine how off-grid solar systems interact with grid electricity consumption once households connect to the grid. This is particularly relevant as national and international policymakers advocate for the expansion of solar solutions as part of electrification strategies in Africa (Kizilcec and Parikh, 2020). Understanding the interplay between solar and grid electricity is crucial for developing sustainable energy policies.

Rwanda's experience with electricity expansion illustrates how consumption patterns are shaped by income and regional factors. National policies must therefore foster inclusive electrification strategies that meet the needs of both low- and high-demand customers. This may involve targeted outreach to low-income households to encourage greater participation in the grid and increased electricity usage, ensuring that electrification benefits all segments of society equitably.

6.2. Conclusion

Our analysis of seven years of electricity consumption data highlights that newly connected households in Rwanda exhibit persistently low consumption levels. Despite tariff reductions for the lowest consumption tier, overall expenditure on electricity among these households declined, suggesting that lower tariffs alone do not drive proportional increases in usage. With average monthly consumption consistently below 10 kWh for the most recently connected households, financial constraints likely limit electricity use, even when tariffs are reduced. This finding implies that tariff cuts alone may be insufficient to drive significant increases in consumption among economically vulnerable households. Further research should explore the contributions of energy-efficient technologies, like LED lighting and smartphones, as well as the role of solar systems in supplementing grid electricity for low-demand households.

A key policy question is how governments can leverage electricity access to stimulate consumption and enhance household welfare. Our findings illustrate the Rwandan government's success in extending grid access to millions of households, but they also suggest that substantial increases in electricity consumption may take longer to materialize than initially expected—consistent with observations in other studies.

From a policy perspective, our analysis underscores the importance of understanding price elasticity in consumer behavior. While our elasticity estimates focus on low-consumption customers, we find that their demand for electricity is inelastic, suggesting that factors beyond price, such as budgetary constraints or competition from alternative energy sources, may limit increased adoption among these households. The observed inelastic response to tariff changes indicates that blanket tariff reductions may not be an effective strategy for increasing consumption. Instead, targeted interventions, such as tailored subsidies, may be needed to encourage higher usage, especially among low-consumption households, which often include low-income populations.

In conclusion, this study highlights the complex interplay between affordability, consumption behavior, and government policy in expanding electricity access. Policymakers must go beyond simply increasing grid connections and focus on fostering sustainable consumption patterns that enhance welfare for economically disadvantaged populations. A multifaceted approach — one that balances affordability with targeted incentives, such as promoting electric cooking — is essential to drive higher electricity usage. Continued research is crucial to understand the impact of energy efficiency measures and alternative sources like solar on grid consumption. This knowledge will ensure that electrification efforts not only improve household well-being but also maintain the financial viability of utility companies.

CRediT authorship contribution statement

Joel Mugyenyi: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bob Muhwezi:** Methodology, Investigation, Formal analysis, Conceptualization. **Simone Fobi:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Civian Massa:** Validation, Formal analysis. **Jay Taneja:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Conceptualization. **Nathaniel J. Williams:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Vijay Modi:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

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

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Appendix A. Data description

A.1. Comparison of household characteristics between REG transaction and non-transaction districts

To investigate socioeconomic differences in household characteristics between districts included in the REG transaction dataset and those not included, we use violin plots (Fig. A.1) to illustrate the distribution of key attributes across these groups.

The room count distributions are relatively similar across both district types, although districts outside the REG transaction dataset show slightly wider variation, suggesting more diverse housing sizes in these areas.

The REG transaction districts have a higher concentration of households with higher expenditure, indicating that wealthier households are more prevalent in these districts compared to those in non-transaction districts.

Household size shows minimal variation across district types, with both groups displaying similar distributions, suggesting that household size is relatively uniform across Rwanda, regardless of transaction dataset inclusion.

In terms of the age of household heads, REG transaction districts tend to have slightly younger household heads on average compared to those in districts outside the transaction dataset, hinting at potential demographic differences between these areas.

These visual comparisons provide valuable insights into the socioeconomic diversity between REG transaction and Non-transaction districts, underscoring modest differences in expenditure and household demographics.

A.2. Consumption patterns among customers with different purchase frequencies

This section presents side-by-side boxplots (Fig. A.2) illustrating the average monthly electricity consumption (in kWh) for customers connected up to 2018. Each subplot shows the distribution of consumption based on the number of months in which a customer made a prepaid electricity purchase, with the x-axis labeled "Months with Purchases" to represent purchase frequency. The primary y-axis displays average monthly consumption (in kWh), facilitating comparisons of consumption patterns across different connection/installation years.

To further capture trends in customer engagement, each subplot includes a secondary y-axis (in red), representing the number of customers by installation year and their corresponding months of active prepaid purchases. This secondary red line plot provides additional insights into shifts in customer participation over time, indicating how engagement levels may align with variations in monthly consumption.

Key patterns emerge from these visualizations. Customers with earlier installation years, such as 2013, generally exhibit higher consumption levels over extended purchase periods. Conversely, customers with more recent installation years, such as 2018, show lower consumption.

Additionally, a recurring pattern is evident, particularly among customers with older installation years: many make a single purchase shortly after connection but subsequently show no further activity. Without more context, it is difficult to determine whether this behavior results from economic constraints, changes in housing status, or other factors affecting continuity in electricity consumption. This trend highlights the potential need for further investigation into customer retention and usage behaviors in newly electrified areas, offering valuable insights for policy interventions to support ongoing engagement.

This section provides further insight into customer consumption patterns, reaffirming previously observed trends, such as higher consumption levels among long-standing customers, alongside new but expected insights, such as lower electricity usage among those with irregular purchase patterns. However, without access to more detailed household-level data, it remains challenging to fully understand the reasons behind infrequent consumption, which could be influenced by economic constraints, seasonal migration, or other household-specific factors.

A.3. Additional descriptive details on low and high consumption customers

This section provides additional descriptive insights into the consumption patterns of low- and high-demand customer groups, as shown in Fig. 7. These plots expand on Fig. 7 by incorporating both average and median monthly consumption, allowing for an additional dimension to view the impacts of tariff changes.

Subplot A.3(a) shows low-demand customers before the 2015 tariff hike. We observe that the median consumption trendline highlights a more noticeable decline in consumption following the tariff increase. This effect is less apparent in the average trendline. For low-demand

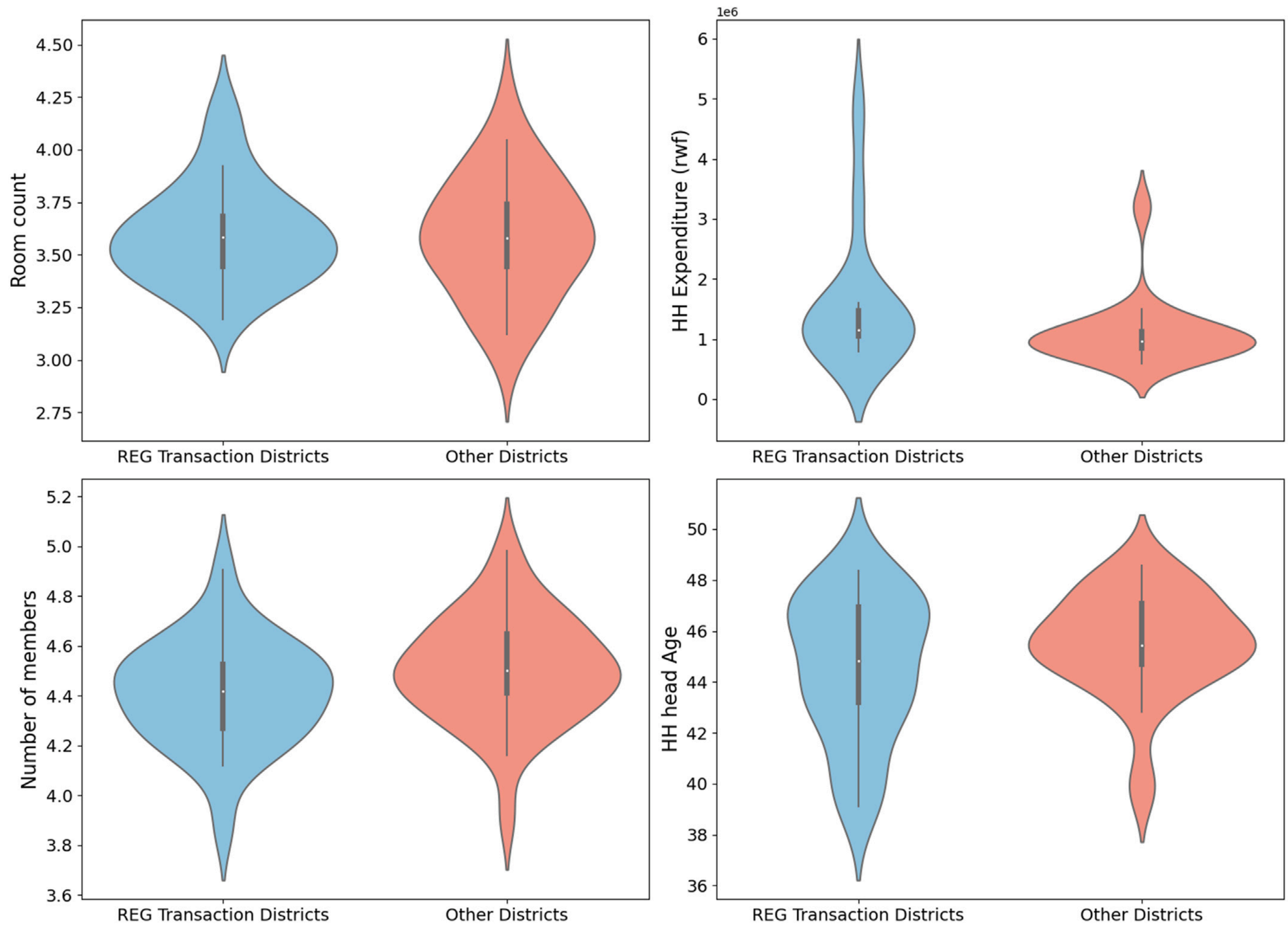


Fig. A.1. Violin plots comparing key household characteristics across REG transaction districts and other districts. The plots illustrate the distributions for Room Count, Household Expenditure (rwf), Number of Household Members, and Household Head Age, revealing variations in these attributes between the two district groups.

customers, the gap between the median and average consumption remains relatively small, generally within 1–2 kWh.

High-demand customers, illustrated in subplots A.3(b) and A.3(d), exhibit a larger gap between median and average consumption. This discrepancy suggests that a subset of high-demand customers consumes significantly more electricity, skewing the average upwards.

Overall, the distinction between average and median consumption across these plots highlights the influence of high-consuming customers on average values, particularly in the high-demand category. For low-demand customers, the average and median consumption trends are closer, reflecting more uniform usage patterns within this group. These insights provide a clearer understanding of how different customer segments respond to tariff adjustments, with high-demand customers exhibiting more variability and sensitivity to tariff changes.

Fig. A.4 illustrates the distribution of low- and high-consumption customers across different districts before the 2015 and 2017 tariff changes. The plots reveal that the majority of customers are concentrated in the capital city, Kigali, where a significant proportion are classified as high-consumption customers according to our categorization. In contrast, most other districts display a higher proportion of low-consumption customers, which aligns with their rural characteristics and more recent electrification efforts. This distribution highlights the urban-rural divide in electricity usage, with rural districts having predominantly low-consumption customers.

Fig. A.5 shows the distribution of low- and high-consumption customers categorized by the number of years since connection to the grid, prior to the 2015 and 2017 tariff changes. In both plots, customers connected for five or more years make up the largest group, with a significant proportion of high-consumption customers. This trend suggests that customers connected earlier have higher consumption. In contrast, customers with fewer years since connection generally have a larger share of low-consumption customers.

Appendix B. Regression analysis

Table B.1 presents regression results analyzing the effects of the 2015 and 2017 tariff changes on monthly electricity consumption. The dependent variable, monthly consumption in kilowatt-hours (kWh), allows for examining customer responses to these tariff adjustments across different consumption groups.

The table includes two models: Column (1) reflects the impact of the 2015 uniform tariff increase, while Column (2) captures the effect of the 2017 block tariff change. Key variables of interest include interactions between the post-tariff period and consumption levels, distinguishing customers consuming below 15 kWh and those consuming above 50 kWh. These interactions highlight the differential effects of tariff changes across consumption groups.

The 2015 tariff increase led to a modest consumption increase among customers consuming less than 15 kWh, while high-consumption customers (above 50 kWh) significantly reduced their usage. Similarly, the 2017 block tariff change showed a positive effect on consumption for customers below 15 kWh but a strong negative effect for those consuming above 50 kWh.

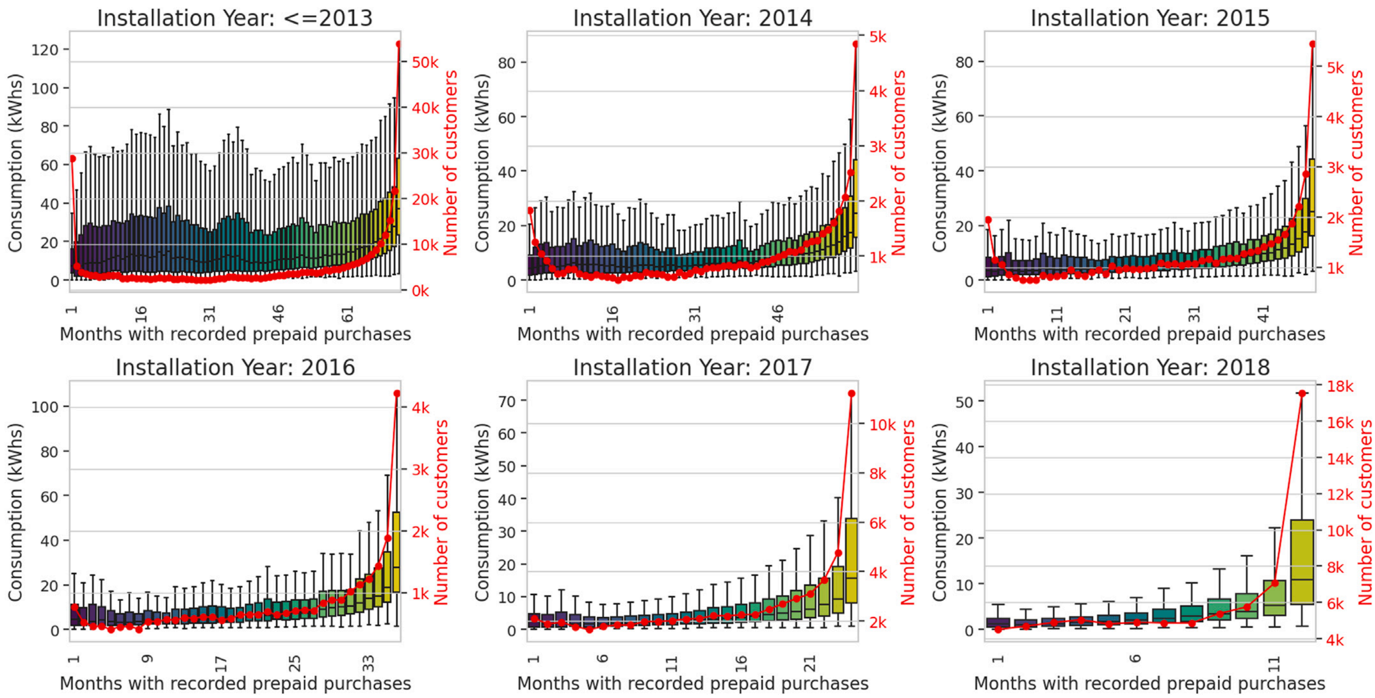
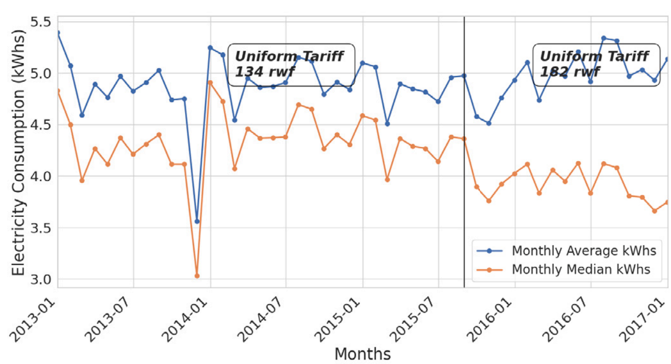
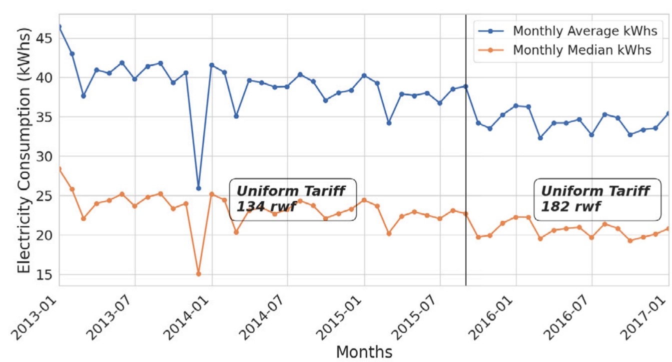


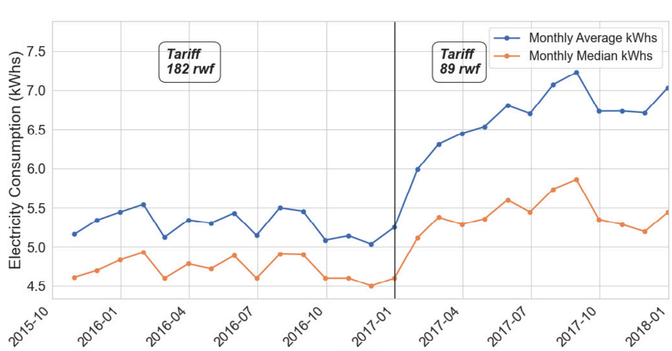
Fig. A.2. Comparison of average electricity consumption and customer counts across different installation years. Each boxplot shows the distribution of average electricity consumption of customers based on installation year and number of active months of consumption since connection to the grid.



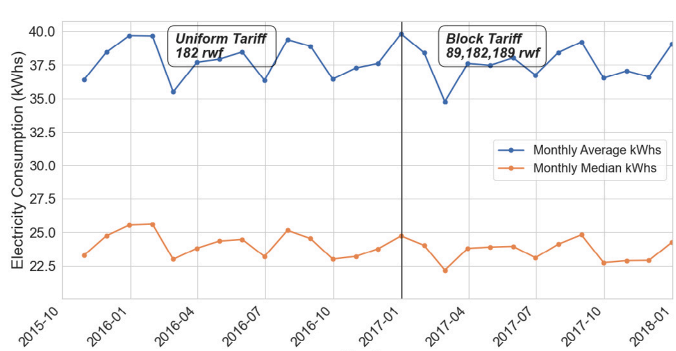
(a) Average and median monthly consumption for 30,004 low-demand customers highlighting the impact of the 2015 Uniform Tariff



(b) Average and median monthly consumption for 147,900 high-demand customers highlighting the impact of the 2015 Uniform Tariff

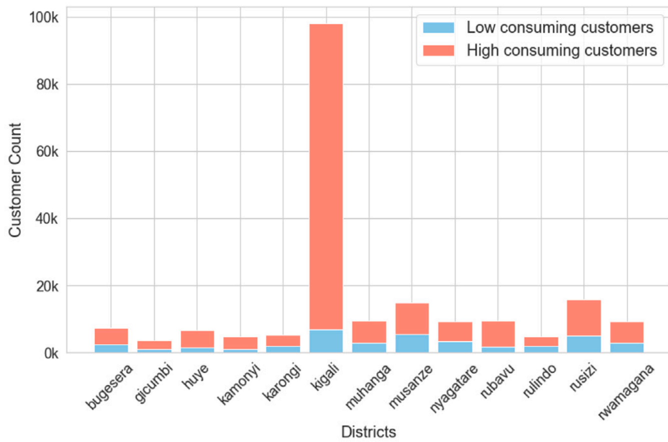


(c) Average and median monthly consumption for 60,848 low-demand customers highlighting the impact of the 2017 Block Tariff

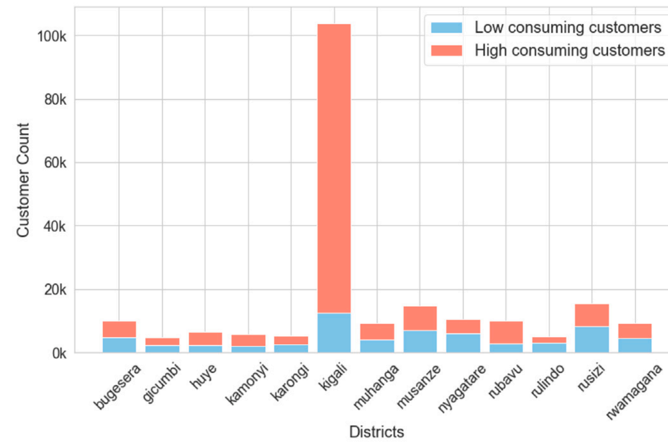


(d) Average and median monthly consumption for 146,021 high-demand customers highlighting the impact of the 2017 Block Tariff

Fig. A.3. Monthly average and median electricity consumption trends for low- and high-demand customers from 2014 to 2018, demonstrating the impact of the 2015 uniform tariff and the 2017 block tariff changes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

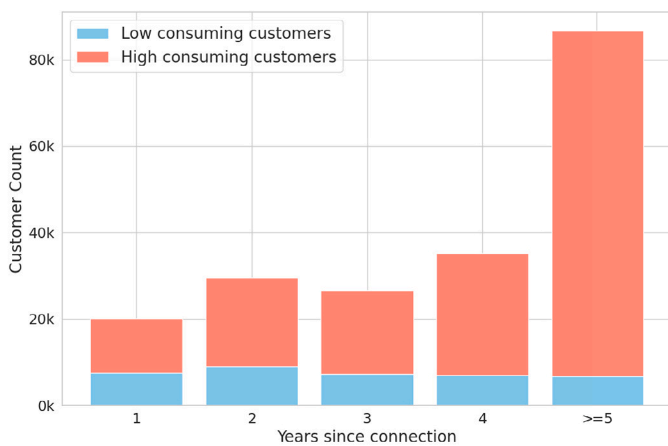


(a) Customer counts by district before the 2015 tariff change

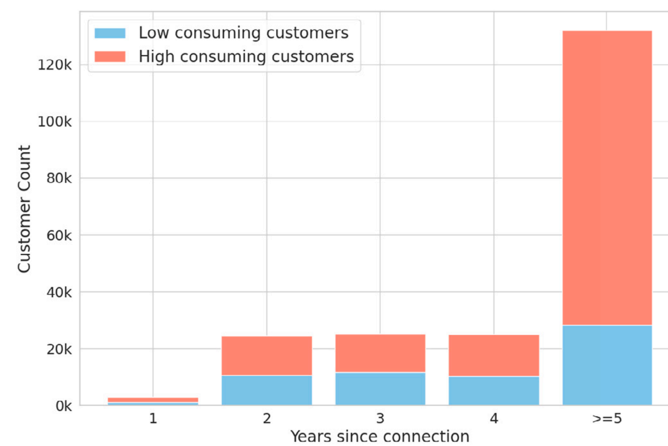


(b) Customer counts by district before the 2017 tariff change

Fig. A.4. Customer counts by district. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



(a) Distribution of low- and high-consumption customers by years since connection before the 2015 tariff change



(b) Distribution of low- and high-consumption customers by years since connection before the 2017 tariff change

Fig. A.5. Customer counts by years since connection. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table B.1
Post shock effect regression results.

	Dependent variable:	
	Monthly consumption (kWhs)	
	2015 tariff change (1)	2017 tariff change (2)
Post Tariff	−3.212*** (0.047)	1.145*** (0.030)
Post Tariff x customers below 15 kWh	3.347*** (0.064)	0.439*** (0.035)
Post Tariff x customers above 50 kWh	−6.189*** (0.065)	−8.821*** (0.045)
Monthly Prepaid Purchase Count	2.115*** (0.003)	1.417*** (0.002)
Months since connection	−0.045*** (0.002)	0.048*** (0.001)
Crude Average	0.002** (0.001)	−0.031*** (0.001)
Log Expenditure	Yes	Yes
Household Members	Yes	Yes
Room Count	Yes	Yes

(*continued on next page*)

Table B.1 (*continued*).

	Dependent variable:	
	Monthly consumption (kWhs)	
	2015 tariff change (1)	2017 tariff change (2)
HH head Age	Yes	Yes
HH Fixed Effects	Yes	Yes
Observations	8,763,153	9,959,854
R^2	0.046	0.066
Adjusted R^2	0.024	0.046
F Statistic	41,645.750*** (df = 10; 8565181)	68,644.950*** (df = 10; 9750196)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

These results highlight the heterogeneous responses to tariff adjustments, with lower-consumption customers benefiting from affordability measures, while higher-consumption customers demonstrated greater sensitivity to price increases. This differentiation offers critical insights for policymakers aiming to design tariffs that balance affordability, equity, and energy conservation.

Data availability

The authors do not have permission to share data.

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