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Investigating households and productive use electricity demand patterns in rural Mozambique

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***Abstract*—Knowledge of electricity demand is key for power supply planning. Most research on electricity demand in sub-Saharan Africa focus on households (HHs) and pay less attention to productive use (PU) sectors. There is also more focus on aggregated demand than demand patterns. Thus, this study investigates electricity demand and its patterns in HHs and PUs in a rural grid-connected region of Mozambique. A bottom-up approach and survey data are used to estimate load profiles. Results show sharply different demand behaviors between HHs and PUs. In HHs, two demand peaks are observed, in the morning and at night, while there is a flat trend during the day. In contrast, demand for PU varies during the day, with a maximum at night. HH peaks occur at the time when residents wake up to prepare for work and housework, while the higher peaks in PU are mainly due to the use of air conditioning and fans in hotels. While the average demand per end-user was higher in PU than in HHs, the aggregated demand is found to be driven by HHs. The findings have implications for infrastructure investments and the allocation of resources to ensure a reliable and sustainable energy supply in rural areas of developing countries.**

Keywords—electricity demand, end-use, bottom-up, rural areas

I. Introduction

Information on electricity demand and its patterns is vital for the planning and operation of electric power systems. Understanding when electricity is consumed in a specific locality enables proper planning for grid infrastructure expansion and dimensioning of mini-grids to ensure a reliable power supply, avoiding under or over-sizing components [1], [2].

The analysis of electricity demand is often categorized into three end-use categories: residential, commercial, and industrial [3], [4]. These end-use sectors exhibit different daily demand profiles throughout, and differences between workdays and weekend load profiles [4], [5]. The residential sector tend to have higher electricity consumption in the mornings and evenings, while productive sectors (industrial and commercial) have peak demand during the daytime period [3]. Residential demand patterns are primarily influenced by human behavior, while industry and commercial are primarily constrained by technical aspects [5]. Commercial demand on the other hand is influenced by economic factors [3].

Research on electricity demand patterns in rural sub-Saharan Africa (SSA) often focuses more on households (HHs) and less attention is given to productive (industrial and commercial) use [3]. Considering demand from both HHs and productive use (PU) provides technical and economic benefits for the supply side by diversifying usage patterns and increasing overall efficiency [6], [7]. While HH demand serves to satisfy basic needs, the PU of electricity offers many advantages. These include increasing revenue through increasing economic activity, improving load factor on the supply side, reducing the energy expenses for households, and expanding electricity access to the public services. It also promotes community development, optimizes facility design, and ultimately contributes to sustainable energy access and overall community well-being [8].

Studies provide aggregate information on electricity consumption without addressing the specific patterns of different user groups [8], [9]. This makes it difficult to develop strategies that are essential to address different needs. More research is needed to capture the variability in consumption patterns [10], [13]. This is essential for effective energy planning and infrastructure development. Moreover, literature shows that there is a lack of understanding of the energy needs and consumption patterns of sectors important to the rural economy, such as agriculture, small businesses, and small industries [11], [12]. In addition, most available studies on rural areas in SSA focus on mini-grids, while less attention has been paid to conventional grid areas [13], [14]. However, due to the high quality and continuous availability of power in the grid, understanding the load profiles would provide a good picture of what the electricity consumption would look like if the capacity of the supply system is high enough to meet the demand.

This study aims at investigating the current electricity demand patterns of households (HH) and productive use (PU) in a grid-connected rural region. To this end, it seeks to answer the following research questions:

- What are the current electricity consumption patterns of HHs and the PU sector?
- Which end-use appliances determine the peak electricity consumption?

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This work is a contribution to the growing body of research on estimating electricity consumption in recently electrified rural areas in developing countries. By providing accurate, context-specific data, it serves as a basis for forecasting and planning future energy demand and ensures that resources are used efficiently and sustainably to meet the actual demands of rural communities in developing countries.

II. METHODOLOGY

The methodology used in this study comprised three main steps. First, a site visit for pre-study assessments was done. This helped in sample size estimation and development of appropriate data collection instruments. Based on this pre-study assessment, a questionnaire was designed. To ensure reliability of the questionnaire, a pilot study was conducted with a small sample to test consistency.

The second step involved sample selection and data collection. Respondents were selected using stratified random sampling, in which the target population was divided into households and PUs strata (TABLE. I). Face-to-face interviews were conducted in HHs and PUs facilities. Interviews were conducted with the head of the household or their representative. The data collected included information on the type, wattage and number of electrical appliances or systems as well as their average operating hours.

Finally, the data were compiled and analyzed. The analysis considered daily load curves for each sector (HH and PU) separately, and then they were aggregated. The development of load curves was based on the methodology suggested by [13], and applying (1)

$$E_i = \sum_m^n P_{m,i} \quad (1)$$

Where E_i is the average load profile for each end-user at time 'i', $P_{m,i}$ is the rated power of the electrical appliance which is on at time 'i', and n is the total number of users.

Then, the total number of users (HHs or PUs) was multiplied by the average electricity demand of a single user in each category. Results were then integrated to determine the total electricity demand. This process followed a bottom-up approach, where the data of individual users was aggregated to determine the total demand.

A. *The study area*

16 de Junho, the main town of the Mapai region, was selected as a case for the study. It is located at latitude -22.6250 and longitude 32.1458 in southern Mozambique. According to national statistics (2023), 13,831 people live in 16 de Junho, with an average of 5.2 people per household and a population density of 19 inhabitants per km^2 [15]. More than 90% of the population depends on subsistence agriculture [15]. Income-generating activities in this area include production and sale of charcoal and informal trade.

In terms of energy use, 85% of the households rely on firewood, 15% combine charcoal and firewood for cooking, and 60% have access to electricity [16], [17]. Electricity in households is mainly used for lighting, cell phone charging, entertainment (CD/DVD players and television), running refrigerators, space cooling (fans), ironing and kettles. The productive use of electricity includes small stores, kiosks, bars, hairdressing salons, metal workshops, water supply, hotels and guesthouses and grain mills.

The study area is located in a hot region with an estimated average annual temperature of 23.8 ºC. Minimum temperatures are about 18.8 ºC, recorded between June and July.

B. *Characteristics of the sample*

The sample for this study consists of 47 HHs and 23 PUs, as shown in TABLE. I .

TABLE. II shows a summary of the main electric loads recorded in HHs and PUs during data collection. The data collected includes the type, total and average number of appliances, rated power (in Watts), operating interval (in hours), as well as the average operating time (in hours).

III. RESULTS AND ANALYSIS

A. *Comparison of electricity consumption patterns of households and productive users*

In this section, results on HHs and PUs are presented and analyzed. Fig. 1 shows the average daily load curve (P_{avg}) for HHs and PUs of the study area. There are two peaks for HH, one between 05:00 and 07:00 in the morning and another between 08:00 and 10:00 at night, with the maximum being reached at night (0.65 kW). This resonates with residents' working and living norms. Thus, appliances such as irons and kettles are likely to be used, and this leads to morning peak. At night, family members are at home and appliances such as TVs, ovens, fans, and lights are usually on causing the evening peak.

The PU load curve shows large variability throughout the day. The maximum peak (1.25 kW) is observed between 07:00 and 10:00 at night. The load variability is probably due to the different types of PUs (small stores, kiosks, bars, hotels/guest houses, water supply, carpentry shops, metal workshops, and grain mills). The maximum peaks are mainly due to the use of air conditioning and fans in hostels and guesthouses, as it is a very hot region.

A comparison of the HH and PU load curves shows that the PU peak load is on average around twice as high as for HHs. The daily average electricity consumption in HH was found to be 2.6 kWh. This is in the range of existing research findings, which varies between 1.6 and 9.5 [18].

TABLE I. COMPOSITION AND SIZE OF THE SAMPLE.

End-users		Number
Households		47
Productive use	Mini shops	3
	Kiosks	3
	Bars	3
	Guest houses	5
	Hair salons	2
	Metal workshops	2
	Water supply	3
	Grain mills	1
	Carpentry	4
Total		73

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TABLE II. TYPE AND FREQUENCY, POWER RATE, AND USAGE TIME OF ELECTRIC LOADS FOR THE SAMPLED USERS.

End-user	Appliances	x	Pm (W)	t (h)	Δt (h)
HHs (n = 47)	Lamps	57	3 - 15	17– 22; 17-05	7.20
	Radio/CD-DVD	25	3 - 140	07 - 21	8.12
	Cell phone	42	5 - 15	19 - 05	4.91
	TV	16	95	09 - 22	9.84
	Fan	18	40 - 60	17 - 5	9.25
	Fridge	19	180- 200	00 - 24	12.00
	Iron	21	1000 - 1200	05 - 07	0.25
	Kettle	14	1000 - 1200	05 – 07; 19 - 21	0.14
	Oven/Stove	3	1500	10 – 12; 19 - 21	1.5
PU (n = 23)	Lighting	382	12 - 40	08 – 17; 17 - 05	10.00
	Cooling Fans	77	40 - 70	11 – 17; 17 - 05	9.25
	Cooling AC	19	850 - 1100	11 – 17; 17 - 05	9.25
	Kettle	78	1000 - 1200	05 – 07; 19 - 21	3.25
	Refrigerators	83	70 - 240	00 - 24	0.07
	Saw	6	570 - 1200	08 - 19	15.00
	Router	4	900	08 - 19	1.00
	Sender	5	2200	08 - 19	3.00
	Planer	6	500	08 - 19	3.00
	Drill	7	800 - 1000	08 - 19	3.00
	Cutting Machine	3	2200	08 - 19	2
	Welding Machine	2	3250	08 - 19	3.6
	Water pump	4	1500 – 2200	06 - 22	16
	hair drier	5	1500	08 - 20	4.25
	hair cutter	4	1500	08 - 20	6.00
	straightener	2	35	08 - 20	1.00

n - sample size; *x* – number of appliances; Pm - mean power rate of the appliances; *t* – average operating window; and Δ*t* average operating hours

Because it is a rural area, and the electricity grid was constructed only five years ago, HH income and electrical appliance ownership are still low and could negatively impact the electricity demand. Despite the diverse nature, most PUs (small stores, kiosks, and bars) often use low-power appliances (refrigerators, lamps, and radios), while water supply, hostels/guest houses, and small industries (carpentry and metal workshops) are responsible for higher electricity consumption.

B. *Total electricity consumption patterns*

Aggregated load curves for HHs, PUs, and both sectors (HHs+PUs) are shown in Fig. 2. The curves for HHs and PUs follow a similar pattern of the average load curves in Fig. 1, but the order of magnitude is different. Because the number of HHs (1000) is much higher than the number of PUs (101), the aggregated demand curve of HHs is by far higher than that of PUs. As a result, the aggregated load (HHs + PUs) follows the HHs patterns. The aggregated maximum peak value is estimated to be 806.95 kW and is observed between 08:00 and 10:00 PM.

TABLE. III shows the summary of total peak demand (P_{Peak}), total energy demand (E) and average energy demand (E_{avg}) in households and productive use sectors in 16 de Junho.

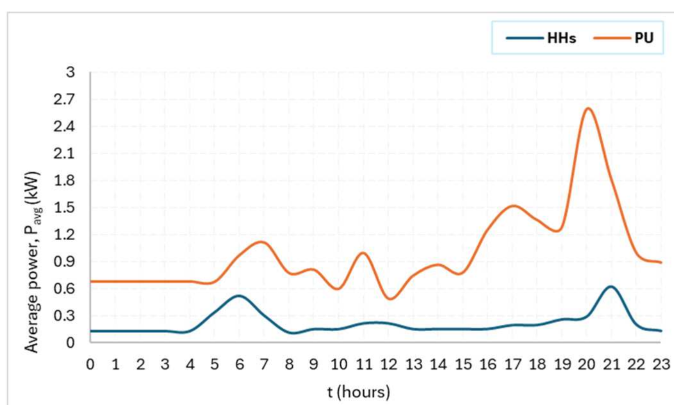

Fig. 1. The average daily load profiles for household and productive user in 16 de Junho.

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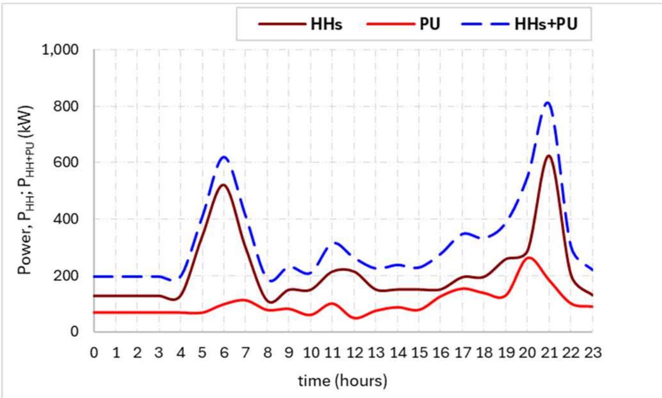

Fig. 2. Households, productive use and total daily load profiles in 16 de Junho. The brown line stands for HHs, the red line for PUs, and the blue dashed line for the aggregated HHs and PUs.

The total HH peak and electricity demand is much higher than for the PUs. However, the daily average energy demand in PU is higher than in HH. The standard deviation of the mean of the average demand is very high, indicating a wide electricity consumption spread.

IV. Discussion

Electricity consumption patterns in 16 de Junho show different behaviors between HHs and PUs. HHs show two consumption peaks which are due morning preparations and evening activities. In contrast, PU shows greater variability throughout the day, with a high peak in the evening due to the use of air conditioning and fans, especially in hostels and guesthouses due to the hot climate in the location. Similar load patterns but lower magnitudes were reported in rural communities of Ghana [4] and Ethiopia [12], however these studies were focused on mini-grids. The magnitude of the peak loads is constrained by the capacity of mini-grids. Contrary to this, national grid capacity can power any type of load.

The comparison of average per user load curves shows that the PU peak loads on average are about twice as high as that of the HHs, but both sectors contribute significantly to electricity consumption. It is noteworthy that despite the establishment of the electricity grid in 2017, the number of users with access and the level of electricity consumption in HHs is still very low. After five years (in 2022), only 40% were connected to the grid, possibly due to limited income and ownership of electrical appliances [13], [14]. While most PUs use low-power appliances, certain sectors such as hotels/guest houses, water supply, and small industries use very high power appliances, thereby contributing significantly to the overall consumption.

The results are consistent with the findings from previous studies [4], [13]. Assessing electricity demand in a rural community, [4] found that HHs were responsible for 78% of the peak load and 82% of the total energy demand in the community. In contrast, in PUs these parameters are estimated at 18% and 11%, respectively. The type of occupation (farming) and behavior have a significant impact on electricity demand in HHs, while the number and type (and size) of PUs are determining factors [4].

TABLE III. Summary of total peak demand, total energy demand, and average energy demand in households and productive use sectors in 16 de Junho.

	P_{Peak} (kW/day)	E(kWh/day)	E_{avg} (kWh/day)
Households	624.21	2,596	2.6 ± 2.27
Productive Use	262	954	25.9 ± 24.83

The higher magnitude of demand in HHs and PUs in 16 de Junho compared to [4] and [13] is likely due to the proximity to road infrastructure and the train station. This facilitates the purchase of electrical appliances in large cities as well as conducting business for longer periods at night, which increases demand. On the other hand, the low electricity consumption is probably because this place has only recently been electrified.

Aggregation of the demand curves shows that the sheer number of HHs significantly influences the overall load pattern, resulting in an aggregated demand curve that reflects the HH consumption pattern. However, it is important to note the high variability of individual electricity consumption within each user group, as shown by the standard deviation of the mean.

V. Conclusion

The analysis of electricity consumption patterns in the 16 de Junho village reveals different behaviors of HHs and PUs. HHs show a bimodal consumption pattern, with peaks in the morning and night, reflecting daily routines and activities. In contrast, PUs show greater load variability during daytime, with a high evening peak.

In HHs, the morning peak is more influenced by the use of irons and kettles, while the night peak is due to the use of TVs, ovens, and fans. For PUs, the maximum peaks are caused by the use of air conditioning in facilities such as hostels and guesthouses owing to the region's hot climate. Hot weather increases demand for cooling equipment, particularly in the PU sectors. This requires a careful consideration of peak periods and resource allocation. The average PU peak load is three times higher than that for households while the total demand for HHs is three times higher than that of PUs. HHs dominate the electricity demand in the rural town.

The policy should focus on supporting energy efficiency in HHs and incentivize PU. By developing sector-specific strategies and promoting energy-efficient practices in households, policymakers can reduce the strain on the electricity grid, improve energy resilience, and promote socio-economic development in 16 de Junho and similar rural areas. Further studies may focus on understanding seasonal variations of electricity demand.

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