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Charcoal consumption patterns and factors affecting the energy choices among low- and middle-income urban households in Maputo City

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ABSTRACT

This study investigates energy use patterns and the factors influencing energy choices among low- and middle-income households in Maputo City, Mozambique, as an empirically grounded, policy-oriented case study of the urban energy transition. Using survey data from 255 households and interviews, we apply the energy stacking model to examine how households combine fuels under limited and unequal access to modern energy. Charcoal use remains widespread: 94% of households rely more or less on charcoal, and use it alongside gas and electricity, despite near-universal grid connection. For low-income households, charcoal use persists because it can be purchased in small quantities daily. In contrast, middle-income households diversify their fuel sources. This mix is related to income, education, household size, and cultural and behavioural factors, supporting the energy stacking model over a linear energy ladder model. The results of a Generalised Linear Model indicate that the use of multiple energy sources is associated with less charcoal consumption. In this context, the article concludes by proposing pathways for policymakers and other stakeholders to reduce charcoal demand within urban households.

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KEYWORDS
Energy stacking model; urban households; Maputo City; energy choices; energy transitions

1. Introduction

Despite the growing use of modern energy sources, traditional sources such as firewood and charcoal still dominate the energy balance in Mozambique (Mahumane & Mulder, 2015). In the southern region of Mozambique, approximately 80% of the total energy consumption is derived from traditional biomass sources (van der Plas et al., 2012; Mahumane & Mulder, 2015; Woollen et al., 2016), with most people in rural areas

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using firewood, while in urban areas, charcoal is the preferred source of energy (Broto et al., 2020). Since 2010, the country's average annual population growth has been almost 3%, and the urbanisation rate has increased from 5% to approximately 36% (Mahumane & Mulder, 2022). This rapid growth has not been accompanied by access to modern energy sources for all urban inhabitants (Mahumane & Mulder, 2022). Consequently, wood extraction rates have increased, particularly around urban centres and toward rural woodlands, driven by population growth and urbanisation (Baumert et al., 2016; Zorrilla-Miras et al., 2018).

It is well established that access to modern energy serves as a powerful catalyst for development (Reddy, 2015). The greatest potential benefit of access to modern energy is its ability to enhance productivity (Fingleton-Smith, 2020). It significantly enhances social development by supporting various critical functions in daily life and economic activities (IEA, 2010). It also improves household productivity (van de Walle et al., 2017). In developing countries, modern energy could reduce people´s time spent in the kitchen and improve health, particularly for women, who are often responsible for domestic activities and are at risk of respiratory diseases from pollution caused by biomass energy (Maji et al., 2021). Transitioning from traditional to modern energy sources is also essential to reducing dependence on biomass.

Two widely used approaches to study the energy transition in developing countries like Mozambique are the energy ladder and energy stacking models. The energy ladder is a three-step model, based on the idea that households follow a straight path of energy choices as their income rises. As households move up the ladder, they shift from traditional energy sources to cleaner, more flexible fuels (Broto et al., 2020). Initially, they use traditional sources; as their income grows, they transition to fuels such as kerosene, coal, and charcoal. In the final stage, they switch to fuels like Liquefied Petroleum Gas (LPG) and electricity (Van Der Kroon et al., 2013). Many studies using the energy ladder model have shown that income is not the only factor influencing energy transitions in developing countries (Peng et al., 2010; Liao et al., 2019; Adetayo et al., 2021; Dutta & Sahu, 2022). Instead, other factors like gender, age, education level, marital status, household size, occupation, farm size, and per capita expenditure also affect energy choices (Adetayo et al., 2021).

Therefore, several studies have shown that the energy ladder is not the most appropriate model for describing household energy choices (Masera et al., 2000; Peng et al., 2010). Instead of a linear pattern where higher income leads to a stepwise fuel displacement, multiple parallel use of different fuels better describes the transition process, representing a mix of energies (Van Der Kroon et al., 2013; Liao et al., 2019). Consequently, the mix of energy sources used in households can be better explained using the energy stacking model (Kowsari & Zerriffi, 2011; Van Der Kroon et al., 2013; Dutta & Sahu, 2022). Some households adopt a blend of energies as an insurance strategy to protect against unstable markets and to maintain cultural practices, while also benefiting from modern fuels. Other households combine energy sources based on preferences for cooking with firewood or charcoal, environmental attitudes, and intergenerational knowledge – the cooking methods of relatives – which significantly influence fuel choice (Gebru & Elofsson, 2023). Peng et al. (2010) identified four key factors in household decision-making under resource scarcity or uncertainty: the economics of fuels and stove types and access to fuels; technical characteristics of cookstoves and cooking practices; cultural preferences; and health impacts.

In southern Mozambique, several studies have examined the impact of biomass energy use, especially charcoal, which is widely consumed in urban areas. Most of these studies focus on the economic and environmental impacts on people involved at the production sites (Baumert et al., 2016; Woollen et al., 2016; Zorrilla-Miras et al., 2018; Lisboa et al., 2020; Sedano et al., 2020). Research conducted among end users in Maputo urban households, using the energy ladder model (Brouwer & Falcão, 2004), found that low-income families mainly use firewood, while higher-income households gradually shift to charcoal, paraffin, gas, and electricity as their income increases. Later, Broto et al. (2020) observed complex energy use patterns within high-income households in Maputo, indicating the suitability of the energy stacking model over the energy ladder. Existing research has a limited extent, covered the household-level, and in Maputo are outdated or primarily focusing high-income groups. Brouwer and Falcão (2004) describe household fuel choices two decades ago, and Broto et al. (2020) analyse energy stacking among urban elites. Additionally, updated data on urban charcoal demand and its determinants are rare since De Koning & Atanassov's (2013) assessment. This creates a gap in understanding current charcoal consumption levels, the factors influencing fuel choices, and the relevance of the energy stacking model for today's low- and middle-income urban households in Maputo.

This study is primarily an empirically grounded, policy-oriented case study of energy choices among low- and middle-income households in Maputo City. It addresses this gap by (i) quantifying current charcoal consumption rates among low- and middle-income urban households in Maputo based on field survey data collected from interviews with 255 households, using a questionnaire that included both closed-ended and open-ended questions, (ii) analysing socio-economic, demographic, and behavioural drivers of fuel choices using descriptive statistics and a Generalized Linear Model (GLM) with gamma distribution and a log-link function, and (iii) examining how household perceptions and practices align with the energy stacking model. By combining survey data with GLM analysis and qualitative insights, the study generates evidence to inform urban energy policies and strategies to reduce charcoal use in Mozambique. At the same time, it contributes to debates on the energy ladder and energy stacking models by demonstrating that, in this context, diversification of energy use is more influential on charcoal consumption than typical socio-demographic variables, thus reinforcing the importance of energy stacking perspectives in urban African settings. This research addresses the following research questions:

1. What energy sources are used, and what are the primary factors influencing the energy consumption patterns among low- and middle-income households in Maputo City today?
2. What factors determine households' choice of specific combinations of energy sources, and how do these patterns relate to the energy stacking model?

This study concludes with recommendations for governments and policymakers on creating targeted interventions to encourage sustainable energy use in urban households and to facilitate a shift away from biomass-based energy sources.

2. Materials and methods

2.1. Study area

Maputo City is situated in southern Mozambique and is the country's capital. The municipality covers an area of approximately 347 km², comprising 64 neighbourhoods divided into seven urban districts: KaMpfumu, KaMaxakeni, Nhlamankulu, KaMavota, KaMubukwana, KaTembe and KaNyaka (CMM, 2016). The study was conducted in the districts of KaMaxakeni, Nhlamankulu, KaMavota, and KaMubukwana, which are comprised of low- and middle-income households, most of the population works in the informal sector and lives in precarious housing (World Bank, 2017). For this study, low-income households were defined as those with a household income (in thousands of meticais (MZN)) between 3 and 15, while middle-income households were defined as those with incomes of 15–40. This classification was inspired by INE (2023), which reported that the average monthly household expenditure in Maputo was approximately 17,000 MZN, and by Němečková et al. (2020), which classifies African social groups based on daily per capita income levels: a floating-income middle class (USD 3–6), a lower-income middle class (USD 6–15), and an upper-income middle class (USD 15–30). These districts also account for a large share of the charcoal trade, both in large markets that sell charcoal in bulk (sacks of approximately 70 kg) and in smaller markets that sell charcoal in smaller, variable quantities (Atanassov et al., 2012). Based on this evidence, there is a higher likelihood that households residing in these areas are charcoal consumers. It is important to note that these four districts account for approximately 90% of the city's population. For simplicity, the term 'Maputo City' will be used throughout the study to refer to these districts (INE, 2023). According to the most recent national census of population and residence conducted in 2017 by the National Institute of Statistics (INE), a projection of Maputo City's population from 2017 to 2035 is presented in Figure 1 (INE, 2023).

2.2. Household energy consumption survey in selected urban Maputo City districts

The data for this research were collected through a field survey conducted in September and October 2023 among low- and middle-income households in Maputo City. The number of neighbourhoods and households was sampled using proportional random

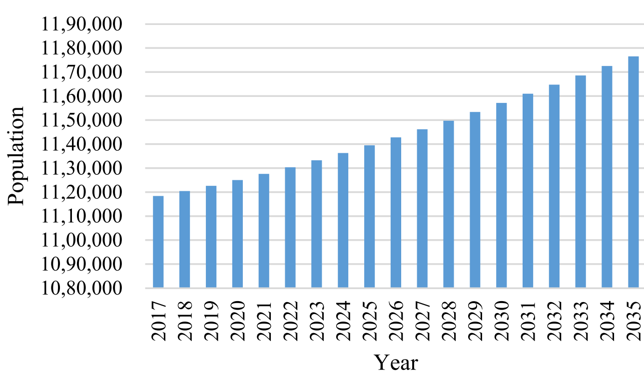

Figure 1. Maputo City population projection from 2017 to 2035 (INE, 2023).

Table 1. Sampled households according to their neighbourhood.

Neighbourhood	Samples	Municipality district	Total of Household	Population
Laulane	18	KaMavota	67768	338296
Maxaquene A	18	KaMaxakeni	40655	202463
Maxaquene C	18			
Polana Caniço A	18			
Bagamoyo	20	KaMubukwana,	68952	331245
Inhagoia A	20			
Inhagoia B	10			
Jorge Dimitrov	27			
Magoanine B	10			
Magoanine C	10			
Chamanculo B	20	Nhlamankulu	28195	131562
Chamanculo C	18			
Minkadjuine	10			
Xipamanine	38			
Total	255		205570	1003566

sampling based on the total number of neighbourhoods and households in the city, resulting in 20 neighbourhoods and 360 households. For each selected neighbourhood, a proportional sample size was calculated, and the corresponding number of households was randomly selected, using Geographic Information System software. Not all eligible households consented to participate in the interview, primarily due to scheduling conflicts. As a result, 255 households were interviewed (Table 1), yielding a response rate of 71% and a non-response rate of 39%. The location of each neighbourhood is shown in Figure 2. In nearly all locations, data were collected from both low- and

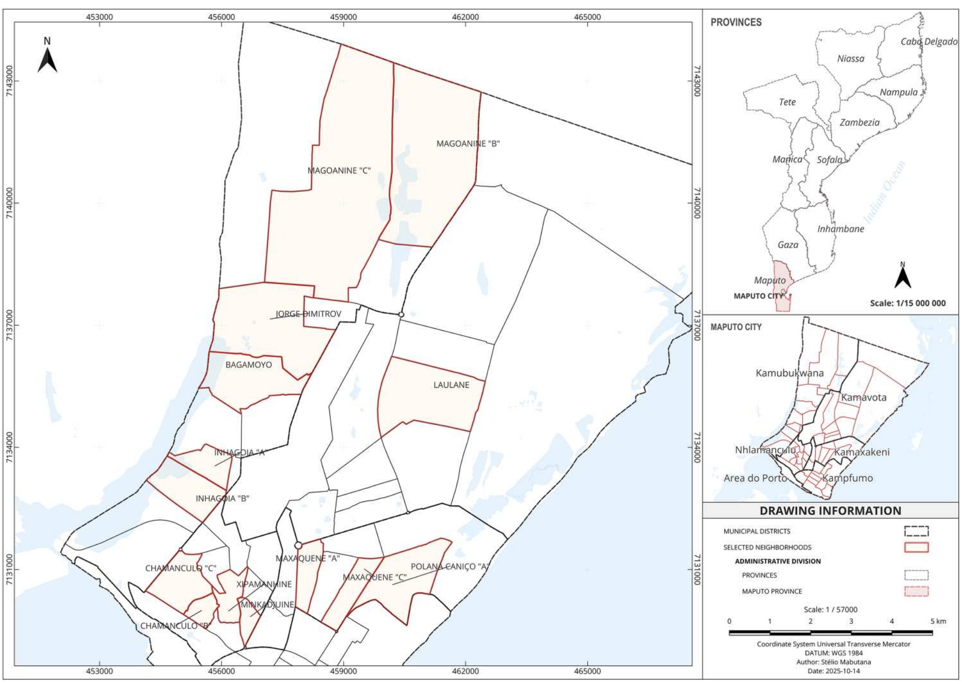

Figure 2. Location of selected neighbourhoods in the study area.

middle-income households, showing that the sample is generally balanced, except at Inhagoia B and Magoanine C neighbourhood, where only low-income households were included (ANNEX A).

The women, who are usually responsible for daily household purchases, were identified as the preferred respondents. If the preferred respondent was not present at the time of the survey, the survey was conducted with another adult household member. Prior to the survey, participants were informed of the questionnaire's scope and purpose. They were made aware that participation was entirely voluntary and that their rights would be respected throughout the process. Furthermore, they were assured that their information would be anonymised, thereby ensuring no risk to their physical or moral integrity, as the data collected would be used solely for this research. A questionnaire was used to collect data on energy consumption for cooking and heating in the selected households. The questionnaire addressed various aspects, including socioeconomic and demographic status, with inquiries about gender, age, education level, income, and household size. Additionally, it included questions on the types of energy used, daily and monthly quantities utilised for each type, and their corresponding expenditures. The questionnaire also included open-ended questions about preferences, habits, and experiences related to choosing charcoal over other energy sources.

2.3. Data analysis

For the data analysis, it was hypothesised that the patterns of energy consumption among the respondents follow the principles defined in the energy stacking model. The energy stacking model suggests that households adopt a combination of energy systems that are influenced by both monetised factors (income, cost, landholding, etc.), and non-economic (household size, gender, age, education, labour, etc.) and behavioural and cultural factors such as food preferences, lifestyle practices, social status, and ethnicity (Kowsari & Zerriffi, 2011). First, descriptive statistics (e.g. frequencies and means) were used to analyse the distribution of fuel consumption among households, focusing on the household head's gender, age, educational level, household head's income, and household size (number of persons). Second, a generalised linear model (GLM) with a gamma and a log link function was used to assess the factors influencing charcoal consumption. The independent variables were tested using different combinations of socio-economic and demographic variables collected. Since the GLM model requires positive values, seven non-charcoal consumer households were excluded from the analysis. Among the explanatory variables, gender, education, energy mix, and income are categorical, whereas age, electricity consumption, and household size are continuous variables. To determine the best model fit, the variable significance was checked, followed by a parsimony model check. The parsimony model evaluates whether the removal of each variable results in a significant deterioration in model fit, using Likelihood Ratio Tests (LRT) to compare the full model with nested models in which one variable is removed at a time. To select the final model, the Akaike Information Criterion (AIC) and pseudo-R^2 for each model were also compared.

The final model included only variables that demonstrated a good fit. This model also includes a categorical variable, energy mix, constructed by coding household responses to the types of energy used for cooking. To enable statistical analysis, each category was assigned an integer value corresponding to a specific energy-use pattern. Households using only charcoal were assigned a value of 1, households using charcoal and gas were assigned a value of 2, households using charcoal, gas, and electricity were assigned a value of 3, households using charcoal and electricity were assigned a value of 4, households using gas were assigned a value of 5, households using electricity and gas were assigned a value of 6, and households using only electricity were assigned a value of 7. The mean annual charcoal consumption per capita (C_c) was determined by multiplying the monthly charcoal consumption (Q in kg) by 12 and then dividing by the size of the household. The demand for charcoal by low- and middle-income households in Maputo City was estimated as the product of C_c, with the percentage of the population that consumes charcoal, according to the findings of the current research.

To enable a comparison of costs across different energy sources, all energy types were converted to a common physical unit, megajoules (MJ), and the effective cost per MJ was adjusted to account for stove efficiency (see van der Plas et al. 2012). The weight of a small bag of charcoal was estimated based on the average weight found in this study, while the weight of large bags provided by Atanassov et al. (2012) was used. To compare the cost-effectiveness of each energy type relative to charcoal, the relative cost was calculated using Equation 1.

$$Relative\ Cost_{energy\ type} = \frac{C_{energy\ type} - C_{charcoal}}{C_{charcoal}} \quad (1)$$

where, $C_{energy\ type}$ is the stove-adjusted cost per MJ, and $C_{charcoal}$is the stove-adjusted cost per MJ of a bag of charcoal.

Furthermore, a qualitative analysis of open-ended interview responses was conducted to explore household perceptions of the factors influencing energy choices. Open coding was initially used to identify categories emerging from participants' perspectives. Previous research, especially studies on the energy stacking model, provided a guiding framework for categorisation. Given the high similarity among responses and the use of an existing conceptual model, the coding process was primarily descriptive rather than interpretive.

3. Results

3.1. Socioeconomic and demographic characteristics of interviewed households

The findings reveal that 55% of interviewed household heads are men, while 45% are women (Table 2). The average age is 48, and many neighbourhoods have household heads older than this (Table 2). This trend is largely attributed to challenges in accessing housing in the city, leading young individuals to remain in their parents' homes even after starting their own families. Consequently, household sizes in most surveyed neighbourhoods surpass the average of 4.8. The results from the interviews show a moderate level of education, with around 57% of the heads of household in these neighbourhoods holding at least a basic secondary education. Regarding net income, most interviewed households earn below the average monthly salary range of 15000–20000 MZN.

Table 2. Socioeconomic and demographic characteristics of interviewed households.

Variables	Categories	Number	%	Mean	Median	SD
Gender of the household head	Female	114	44.7			
	Male	141	55.3			
Age of the household head	Age 22–34	38	14.9	48.4	47.0	13.2
	Age 35–47	90	35.3			
	Age 48–60	78	30.6			
	Age 61 and over	49	19.2			
Educational level of household head	No formal Education	17	6.7	3.6	4.00	1.5
	First Grade Primary Education	61	23.9			
	Second Grade Primary Education	31	12.2			
	Basic Secondary Education	66	25.9			
	High School	52	20.4			
	University Education	28	11.0			
Household Size (no. of persons)	1–2	28	11.0	4.8	4.0	2.3
	3–5	152	59.6			
	6–8	56	22.0			
	over 8	19	7.5			
Household income (in thousands of MZN)	3–5	47	18.4	2.8	3.00	1.3
	5–10	65	25.5			
	10–15	63	24.7			
	15–20	42	16.5			
	20–40	38	14.9			

3.2. Fuel choice/fuel consumption and its relative prices

All surveyed households have access to the national electricity grid. Approximately 94% use charcoal as a cooking fuel, either partially or exclusively (Table 3). Specifically, 35% of the respondents rely solely on charcoal for cooking, 29% use a combination of charcoal and gas, and 16% employ a combination of three energy sources: charcoal, electricity, and gas. Notably, only a small percentage (1%) uses only electricity for cooking. Around 62% of the households use a combination of fuels.

Fuel prices differ significantly, and for charcoal, the difference between small and large quantities results in a 22% higher price for the smaller quantities (Table 4). The weight of small charcoal bags ranged from 0.968 kg to 2.200 kg, with a mean weight of 1.544 kg (SD = 0.342). The corresponding prices ranged from 25 MZN to 60 MZN, with an average of 44.55 MZN per bag (SD = 12.11). The price of a bag of charcoal in the sample ranged from 1,200 MZN to 2,000 MZN, with a mean of approximately 1,548.09 MZN (SD = 182.60). Charcoal sold in smaller bags (mean weight: 1.6 kg) had the highest unit price at 27.5 MZN/kg, while larger bags (mean weight: 68.5 kg) were significantly cheaper at 22.6 MZN/kg. This pattern indicates that households purchasing

Table 3. Number and percentage of households using different fuel combinations for cooking.

Combinations	N	%
Charcoal	89	35
Charcoal and Gas	80	31
Charcoal and Electricity and Gas	39	15
Charcoal and Electricity	37	15
Gas	4	2
Electricity and Gas	4	2
Electricity	2	1
Total	255	100

Table 4. The average cost of energy in uniform units of MJ for each type of fuel and their relative prices (meticais/MJ) in Maputo city.

Fuel Type	Unit of measurement	Selling unit	Price (MZN)/ selling unit	Price (MZN)/ Unit	Quantity in MJ/fuel unit **	Price (MZN) /MJ	Stove efficiency-eff (%)	Price (MZN)/MJ (including stove eff)	Relative Cost (%)
Charcoal (small quantities)	kg	1.6	44	27.50	29	0.95	0.3	3.16	22
Charcoal (Bag)	kg*	68.5	1550	22.63	29	0.78	0.3	2.60	0
Gas	kg	9	855	95.00	42.7	2.22	0.65	3.42	32
		11	975	88.64	42.7	2.08	0.65	3.19	23
		14	1250	89.29	42.7	2.09	0.65	3.22	24
Electricity	kWh	1	8.4	8.40	3.6	2.33	0.8	2.92	12

*Mean weight of charcoal bag found in Atanassov et al. (2012).
**The energy conversion coefficient (megajoule per unit); the efficiency of the stove in percentages, source: van der Plas et al. (2012).

smaller quantities face higher unit costs. A similar trend was observed in gas pricing, with the small cylinder having the highest price: 9 kg cylinder, 855 MZN (95 MZN/kg); 11 kg cylinder, 975 MZN (88 MZN/kg); and 14 kg cylinder, 1250 MZN (89 MZN/kg). For electricity, the reported price was 8.4 MZN per kilowatt-hour (kWh).

When comparing energy prices by energy content (MZN per megajoule, or MZN/MJ), large-bag charcoal emerges as the most economical fuel at 0.78 MZN/MJ. This is followed by LPG (ranging from 2.08–2.22 MZN/MJ) and electricity at 2.33 MZN/MJ. However, incorporating thermal efficiency into the analysis increases the cost per unit of useful energy (MZN/MJ_eff). Even with efficiency adjustments, large-bag charcoal remains the most affordable option at 2.60 MZN/MJ_eff. Followed by electricity, benefiting from an estimated 80% device efficiency, costs 2.92 MZN/MJ_eff. High-efficiency stoves save more energy, which is why, when efficiency values are taken into account, gas becomes more expensive than electricity (Table 4). Using large-bag charcoal as the reference (0%), the relative cost metric reveals higher effective costs for other fuels: Small-bag charcoal (21.53%), gas of 14 kg (23.69%), gas of 11 kg (22.79%), gas of 9 kg (31.60%) and electricity (12.14%). These values indicate that, even after accounting for efficiency gains, all non-reference fuels have higher effective costs per MJ than charcoal.

The annual per capita charcoal consumption for cooking in the sampled household of Maputo City was estimated to103 kg/year, giving an annual total demand for charcoal by households in Maputo City is 98,748 tons. According to studies by De Koning & Atanassov (2013), the annual charcoal demand for the cities of Maputo and Matola was 297,360 tons. Considering that in 2012 Maputo City accounted for 60% of the total population of Maputo and Matola cities (INE, 2012, 2014). The annual charcoal demand for Maputo city was approximately 178,000 tons. Based on this figure, it can be estimated that the demand for charcoal has decreased by about 45% over the past 10 years, however, these comparisons are exploratory due to differences in sampling design.

3.3. Household perceptions about factors influencing energy choice among interviewed households

The survey questionnaire included open-ended questions to let households share their perceptions of the factors influencing their daily energy choices. Some quotations from household responses are also included, these quotations appear immediately after the relevant section descriptions.

According to respondents, the main sources of energy in the urban areas of Maputo City are charcoal, gas, and electricity. All households are connected to the grid and mainly use electricity to light their homes and operate basic appliances such as televisions, radios, refrigerators, kettles, stoves, and other electric devices. For cooking, energy sources are used individually or in combination, as shown in Table 3. The frequency of charcoal use for cooking varies by household; those who rely solely on charcoal cook with it daily. In contrast, households that combine it with other energy sources use charcoal from 1 to 5 days a week, depending on the availability of these sources and their dietary preferences.

'*We use electricity to watch television and for lighting at night, charcoal to cook every day, and we do not have other energy sources for now*'.

For those who use charcoal every day, many are self-employed, and their income depends on daily sales. According to them, although charcoal is not as cheap as other energy sources, it can be bought daily in small bags. Because of their low monthly income, they cannot afford to buy equipment to use gas, which they believe is generally cheaper than other energy sources.

'*I use energy this way because it is not easy to buy electricity for cooking; it is easier to buy charcoal in small plastic bags available near my home*'.

'*We use energy this way because of our financial situation, and because the price of a gas stove is somewhat higher compared to a charcoal stove*'.

When asked if they would keep using charcoal if other energy sources were affordable, many said they would use it partially or alongside other options. A lot of respondents see gas as a better alternative because it is economical, easy to operate, quick for cooking, and convenient in all weather conditions, whereas charcoal is hard to use on rainy days.

However, some households prefer to use electricity because they believe it is much safer than others, while some continue to use charcoal due to a lack of knowledge about gas installation and its safety concerns.

'*Yes, I would include it, but not for daily use. Only on festive occasions, so as not to overburden the use of gas*'.

People who use charcoal along with one or two other energy sources often find it tiring and less sanitary. Therefore, many prefer gas for everyday cooking. Charcoal is kept for special occasions to prepare certain foods that taste better when cooked over charcoal, such as grilled items and dishes for celebrations. It is also used for cooking dishes that demand more fuel, like beans. Combining charcoal with another energy source helps save gas and provides an alternative when the gas runs out.

'*They use electricity for watching (television), lighting, heating water, and frying eggs; gas is used more frequently for cooking, and charcoal is used to cook foods that take longer*'.

3.4. Factors influencing energy choice and charcoal consumption rates

The socioeconomic and demographic factors influencing monthly energy costs in meticais (MZN) are shown in Figure 3. The energy mix, which reflects the number of energy sources used in a household, is clearly linked to education and income levels ($r = 0.27$ and $r = 0.24$, respectively), as presented in Table 5. Income also significantly affects expenditures on gas and electricity, with positive correlations for electricity ($r = 0.51$) and gas ($r = 0.40$). Higher educational levels are positively associated with modern energy use, indicated by gas ($r = 0.40$) and electricity consumption ($r = 0.20$). These results suggest that as education and household income rise, families tend to diversify their energy sources rather than depend on just one fuel. Income is also positively related to annual charcoal consumption per capita ($r = 0.10$), showing continued use of charcoal along with modern fuels. Conversely, charcoal consumption ($r = -0.16$) decreases with higher education, indicating a shift from traditional to modern energy sources. Household size correlates positively with charcoal use ($r = 0.16$) and negatively with energy diversification ($r = -0.13$), though larger households tend to have lower annual charcoal consumption per person ($r = -0.46$), likely due to shared use.

Tables 6a and b present the results of the first and second model fits. The variable energy mix was the most statistically significant among the other variables, with its

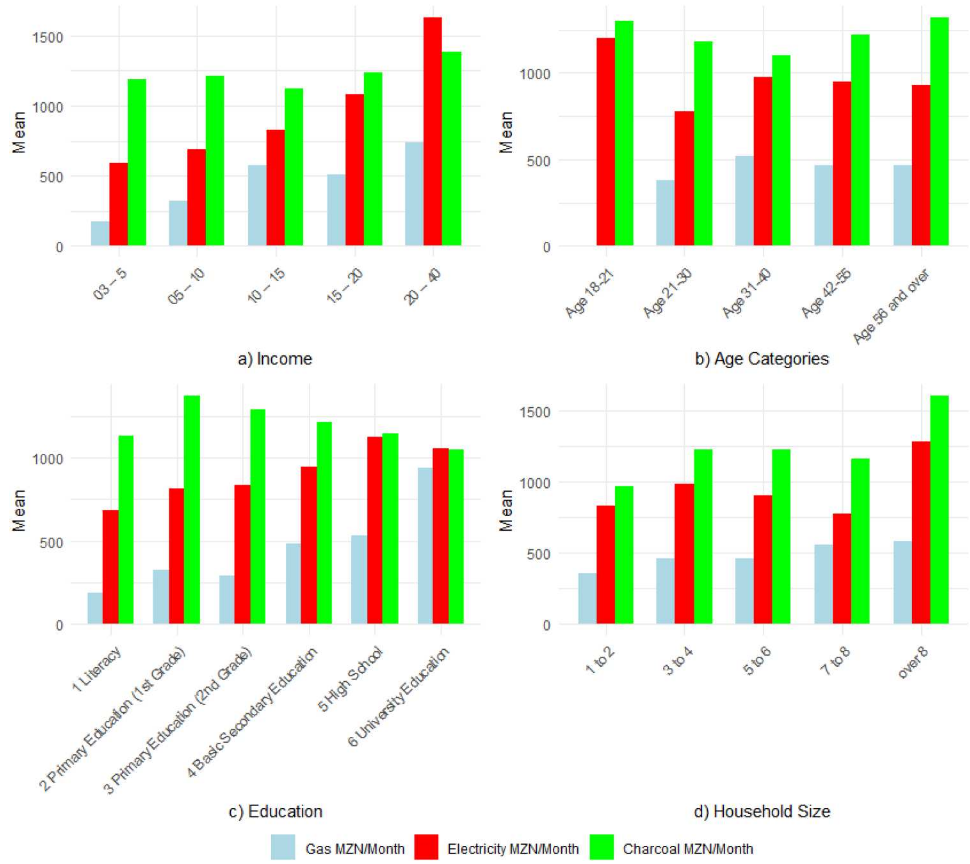

Figure 3. Monthly average household energy costs in meticais (Mozambican currency, 1 MZN = 0.015 US dollars) across different energy source categories. The panels show energy source cost distribution in relation to: (a) monthly income in MZN, (b) head of household's age, (c) head of household's educational level, and (d) household size.

sixth category showing a p-value < 0.001 in both models. No statistically significant associations were observed for the variables gender, education, income, age, electricity and gas consumption, or household size ($p > 0.10$). Overall, the results indicate that the energy mix, rather than sociodemographic characteristics, is the main factor predicting household-level charcoal consumption, suggesting that as households diversify their cooking energy sources, they tend to reduce charcoal consumption. It was observed that

Table 5. Correlations between different factors influencing charcoal consumption.

	Electricity MZN / Month	Gas MZN/ Month	Charcoal MZN/ Month	Annual Charcoal per capita	Energy Mix
Gender	0.111	0.094	0.000	−0.003	0.017
Age	−0.015	−0.060	0.111	0.010	−0.094
HH Size	0.084	0.024	0.161*	−0.459**	−0.129*
Education	0.196**	0.389**	−0.163**	−0.085	0.272**
Income	0.506**	0.399**	0.027	0.091	0.242**

Correlation significant levels: '**' 0.01, '*' 0.05.

Table 6. The estimates of the GLM mith Gamma and a log link function.

(a) 1st model

	Estimate	Std. Error	t value	Pr(>|t|)	Signiant level
(Intercept)	3.72979	0.19778	18.859	< 2e-16	***
Gender	0.01513	0.07047	0.215	0.8302	
Education 2	0.25816	0.15609	1.654	0.0996	.
Education 3	0.2362	0.16756	1.41	0.1601	
Education 4	0.22494	0.15907	1.414	0.1588	
Education 5	0.15886	0.16879	0.941	0.3477	
Education 6	0.23808	0.19556	1.217	0.2248	
Energy Mix 2	−0.50006	0.26827	−1.864	0.0637	.
Energy Mix 3	−0.45135	0.27005	−1.671	0.0961	.
Energy Mix 4	−0.20899	0.10685	−1.956	0.0518	.
Energy Mix 5	−0.12733	0.43263	−0.294	0.7688	
Energy Mix 6	−2.24001	0.44298	−5.057	9.15e-07	***
Income 2	0.07712	0.11212	0.688	0.4923	
Income 3	0.06241	0.12031	0.519	0.6045	
Income 4	0.08257	0.13224	0.624	0.533	
Income 5	0.24549	0.14899	1.648	0.1009	
Age	0.01751	0.0376	0.466	0.6419	
Electricity consumption	0.04512	0.04138	1.09	0.2767	
Gas consumption	0.01034	0.13533	0.076	0.9392	
Household size	0.05336	0.03447	1.548	0.1231	
Null Deviance	Residual Deviance	Dispersion Parameter	AIC	Pseudo − R^2 (Deviance − based)	
104.28 (df = 233)	90.16(df = 214)	0.25	2162.56	0.14	

Significance: *** $p < 0.0010$; ** $p < 0.01$; *$p < 0.05$; . $p < 0.10$ '.' 0.1 ' ' 1

(b) 2nd model

	Estimate	Std. Error	t value	Pr(>|t|)	Signiant level
(Intercept)	3.93435	0.15033	26.172	< 2e-16	***
Energy Mix 2	−0.47641	0.25731	−1.851	0.0654	.
Energy Mix 3	−0.4483	0.25977	−1.726	0.0858	.
Energy Mix 4	−0.18329	0.10241	−1.79	0.0749	.
Energy Mix 5	−0.13938	0.41931	−0.332	0.7399	
Energy Mix 6	−2.23042	0.42563	−5.24	3.74e-07	***
Income 2	0.07829	0.10543	0.743	0.4585	

(Continued)

Table 6. Continued.

(b) 2nd model					
	Estimate	Std. Error	t value	Pr(>|t|)	Signiant level
Income 3	0.06565	0.1122	0.585	0.559	
Income 4	0.08228	0.12335	0.667	0.5054	
Income 5	0.24866	0.13901	1.789	0.075	.
Electricity consumption	0.04245	0.03986	1.065	0.288	
Gas consumption	0.0132	0.12654	0.104	0.917	
Household size	0.05464	0.03346	1.633	0.1039	
Null Deviance	Residual Deviance	Dispersion Parameter	AIC	Pseudo – R^2 (Deviance – based)	
104.28 (df = 233)	91.09(df = 221)	0.24	2151.12	0.13	

Significance: *** $p < 0.0010$; ** $p < 0.01$; *$p < 0.05$; . $p < 0.10$ '.' 0.1 ' ' 1 the AIC improves when gender, age, and education were removed, indicating that their explanatory contribution is limited. The pseudo-R^2 remained unchanged between the two models at approximately 13%, indicating that excluding these variables does not compromise the model's explanatory power. According to this criterion, the model 6b was chosen for further analysis.

4. Discussion

The objective of this study was to characterise current patterns and the factors influencing energy choice among low – and middle-income households in Maputo City. By providing updated charcoal demand estimates and documenting current energy stacking patterns among these households, this study fills the empirical gap left by earlier work that focused either on production regions or on elite urban households. Charcoal, gas, and electricity were identified as the main energy sources used by the surveyed households, with about 62% using a combination of these. Charcoal is the most used energy source, with approximately 94% of households relying on it either partially (59%) or exclusively (35%). This aligns with Broto et al. (2020), who identify charcoal as the dominant energy source in urban areas of Mozambique.

None of the sampled households reported using firewood, suggesting a shift away from this source. In the past, there has been a trend of transitioning from firewood to higher-quality fuels, including charcoal (Brouwer & Falcão, 2004). Similarly, a recent study by GreenLight (2022), found that only about 0.5% of households still use firewood for daily cooking. This shift may be driven by the limited availability of firewood in Maputo City compared to other sources. For instance, charcoal is readily available in markets near residential areas. Additionally, firewood is time-consuming to use, as it requires significant effort to start and maintain a fire, making it less convenient than charcoal. A similar trend has been observed in Zambia's urban areas, where the exclusive use of firewood has significantly declined due to the increasing distances required to collect it, a trend exacerbated by deforestation (Mulima et al., 2025).

4.1. Factors influencing the fuel choice

The study shows that the factors affecting energy choices among low – and middle-income households in Maputo City are complex, with income being the most crucial factor for the poorest households. At this level, households have few options for managing energy costs for daily needs. A common approach is to buy small bags of charcoal every day, though this is relatively expensive per unit. Conversely, for middle-income households, income is not the only factor influencing energy choice. Other important factors include non-economic aspects such as the age of the household head, education level, household size, and behavioural and cultural traits. Our findings further support the idea that there is no simple 'energy ladder' progression in Maputo. Even with higher income, middle-income households do not fully shift from charcoal to gas or electricity for cooking. Instead, as income increases, households tend to combine various energy sources, consistent with the energy stacking model (Masera et al., 2000; Peng et al., 2010; Mulima et al., 2025).

In the present study, gas is the second most used fuel and is strongly associated with individuals who have a high level of education and higher income. According to the respondents' perceptions, this group has greater awareness of the benefits of using gas. Additionally, they can afford the initial investment required to purchase gas cylinders and stoves, which is an obstacle for low-income individuals. Nevertheless, around 46% of households use gas in combination with charcoal as a strategic approach to meet their cooking energy needs. This strategy has been reported by Kowsari & Zerriffi (2011), who show that many households maintain traditional energy systems as a form of insurance against potential failures in modern energy supply. By diversifying their energy use, households also reduce their vulnerability to fluctuations in modern energy prices.

Electricity is the least frequent option for cooking fuel. Like gas, it is mainly used by households with higher income and more educated people. However, most respondents see electricity as relatively costly for cooking. As a result, its role in household energy use is limited, and it is mostly used for quick cooking tasks like boiling water for tea or baths, which matches the findings of Mudombi et al. (2018).

Considering that charcoal is the most used fuel for cooking among the surveyed households, the analysis of factors associated with charcoal consumption reveals that the energy mix variable is highly significant. The GLM analysis shows an estimate of −2.24 (p-value < 0.0010), this indicates an association between households that diversify their energy sources and a reduction in their monthly charcoal consumption for cooking This reduction can be attributed to the fact that in higher-income households, charcoal is not used daily and is often reserved for special occasions or for preparing specific dishes that require substantial fuel. As noted by Strong & Silva (2023), charcoal is typically used to cook foods such as beans and stewed meats, which are common in the diet of Tete, a city in central Mozambique. These types of meals require long cooking times, and modern energy sources are often considered too expensive for such prolonged use (Van Der Kroon et al., 2013).

In the present study, a modest correlation was observed between age and charcoal consumption ($r = 0.11$). About 16% of household heads aged 50 or older use multiple energy sources. This indicates that, even with access to modern energy options, people in this age group often resist changing their cooking practices, either because of long-standing habits of cooking with charcoal or a preference for the distinctive flavour charcoal adds to food. Similarly, Wijayarathne et al. (2023) found that older household heads are less likely to switch to clean energy sources. Additionally, Broto et al. (2020) noted that individuals over age 50 tend to use charcoal more often than those under 50.

4.2. Strategic pathways to affordable and sustainable energy access for urban households in Maputo City

In Mozambique, most programmes, such as BRILHO, (n.d.); MIREME (2019), have been implemented to address Sustainable Development Goal 7 (SDG 7), which aims for universal access to affordable, reliable, sustainable, and modern energy for all by 2030. These initiatives mainly focus on rural areas because of their significant energy needs. It is estimated that only 27% of the population has access to electricity, with most of those living in urban areas. This means approximately 21.5 million people still depend on inefficient lighting and energy solutions (Linden & Atanassov, 2017). While expanding the rural electrification grid is necessary, it neglects the energy needs of people living in urban and peri-urban areas. Therefore, developing targeted strategies that not only focus on rural energy expansion but also address the challenges urban households face in achieving SDG 7 is crucial. By quantifying current charcoal demand and recognising energy mix as the main lever, this study provides evidence for designing urban-specific interventions (e.g. PAYG LPG, promotion of efficient electric stoves, and information campaigns on effective energy costs).

The demand for charcoal in Maputo City has dropped by about 45% compared to the findings of De Koning & Atanassov (2013). This decrease is probably due to more households in the city using gas. These results indicate that strengthening policies to encourage gas use for cooking could further decrease charcoal demand. Such efforts would help protect forest resources and promote more sustainable energy habits.

When evaluating the unit cost of useful energy in megajoules (MJ), and accounting for stove efficiency, charcoal sold in big bags is currently the most affordable energy source, followed by electricity, then small bags of charcoal, with gas being the most expensive. However, households generally lack information about the real costs and benefits associated with their energy choices, as well as how energy is utilised within households. To address this knowledge gap, it is recommended that the government first promote targeted awareness campaigns aimed at low-income households. These campaigns should aim to educate households about energy efficiency and encourage diversification of energy sources.

In terms of energy efficiency, it is important to develop mechanisms that improve access to affordable modern cooking technologies, like gas or electric stoves, which are more cost-effective than charcoal. These technologies could be introduced not as immediate replacements but as complementary options, giving households time to adapt gradually. Addressing affordability could also involve offering smaller quantities of gas than are currently available, allowing low-income households to purchase it, like how they buy charcoal. Additionally, it is crucial to support research and development of affordable, efficient cooking technologies that meet households' specific needs, while recognising and respecting cultural cooking practices.

Mozambican policymakers and stakeholders could learn from projects such as Pay-as-you-go (PAYG) liquefied petroleum gas (LPG) initiatives implemented in some African countries (Perros et al., 2021; Shupler, et al., 2021a; Shupler, et al., 2021b; Ulsrud et al., 2025). PAYG LPG is a new technology that enables urban households to purchase LPG in small amounts, thereby addressing affordability (Perros et al., 2021; Ulsrud et al., 2025). A pilot study conducted by Perros et al. (2021), showed that most participants transitioned from charcoal to PAYG LPG as their primary cooking fuel and continued using the service throughout the pilot period. This model particularly benefited households with fluctuating, relatively low incomes, which typically face challenges affording full-cylinder purchases (Ulsrud et al., 2025). Additional advantages include improved safety, time savings, and convenient cylinder delivery (Shupler, et al., 2021b).

For middle-income households, who already tend to use a mix of energy sources, the goal should be to gradually replace charcoal, often used as a secondary source, with more efficient and sustainable alternatives, such as electric stoves. However, achieving this shift requires a clear and coordinated effort by policymakers. This includes not only disseminating information on energy efficiency and cost-effectiveness but also ensuring the quality and regulatory compliance of stoves and appliances available on the market. Also economic means for stimulating the use of modern energy sources should be considered.

5. Conclusion

This study highlights that energy use patterns among low – and middle-income households in Maputo City are shaped by a complex interplay of economic, social, and cultural factors. Although charcoal remains the dominant cooking fuel, the widespread adoption of energy stacking, rather than a linear transition toward cleaner fuels, among middle-income households, suggests that affordability, behavioural preferences, and cultural practices continue to strongly influence household energy choices. Income, education, and household size also play a role in energy diversification, while perceptions of cost and practicality limit the uptake of electricity and gas for everyday cooking. In contrast, for low-income households, income is the most critical factor, as financial instability restricts access to long-term, cheaper energy sources.

By updating charcoal consumption figures and highlighting the crucial role of the energy mix in shaping fuel choices, this study directly addresses the lack of recent household-level data for Maputo's low and middle-income urban residents and provides concrete policy entry points. However, the study is constrained by its focus on urban low – and middle-income households in a single city and by relying on self – reported consumption and perceptions, which may introduce recall bias. Future research should explore longitudinal changes in household energy strategies, examine intra – household decision dynamics, and assess the effectiveness of emerging interventions such as PAYG LPG and efficient electric cooking technologies.

For policymakers, the results point to several actionable pathways: broaden access to affordable modern cooking appliances; support flexible payment mechanisms for gas; expand awareness campaigns that clarify real energy costs; and invest in urban – specific energy strategies that acknowledge cultural cooking needs and existing energy stacking practices. Such targeted approaches can accelerate progress toward SDG 7 while reducing charcoal dependence and promoting more sustainable and equitable energy transitions in Maputo City.

Disclosure statement

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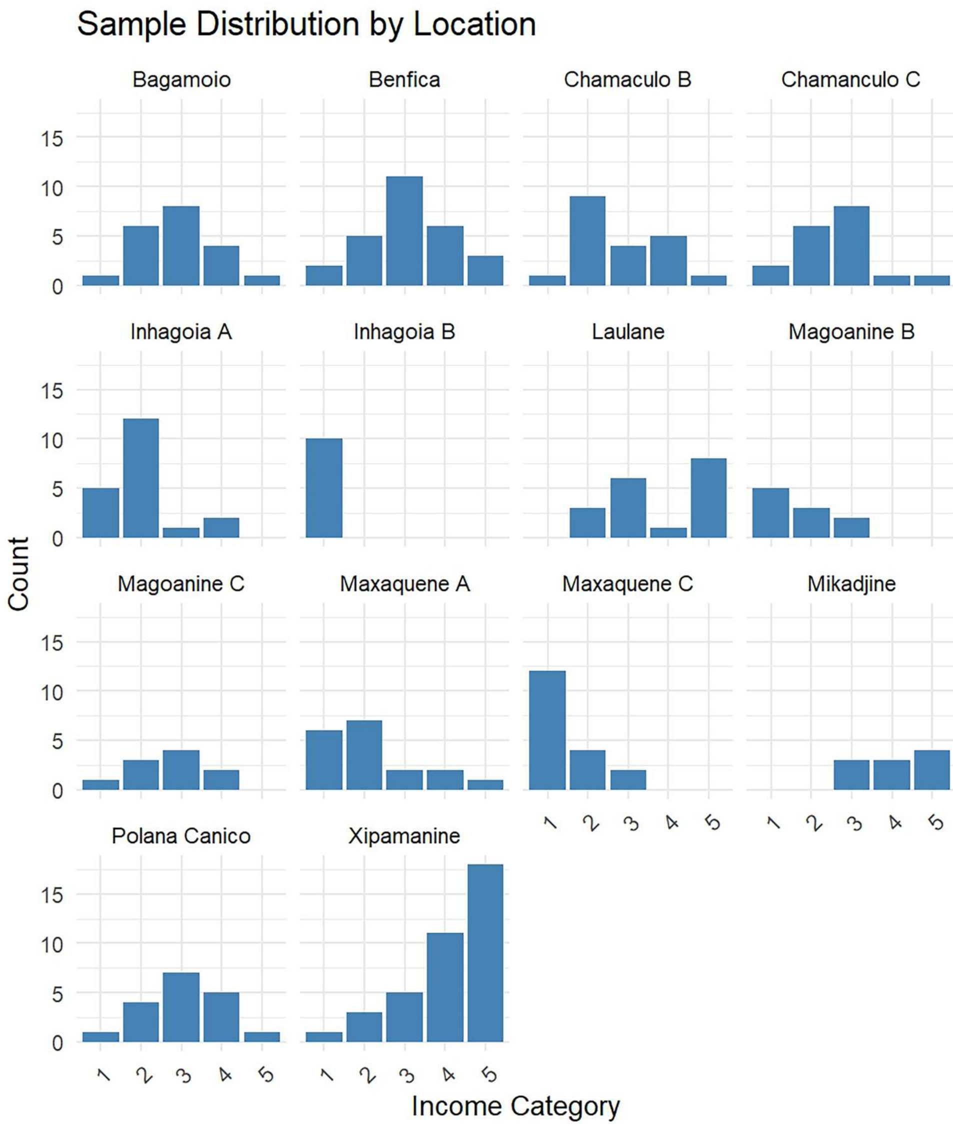
Annex A


Sample Distribution by Location
Bagamoio
Benfica
Chamaculo B
Chamanculo C
Inhagoia A
Inhagoia B
Laulane
Magoanine B
Magoanine C
Maxaquene A
Maxaquene C
Mikadjine
Polana Canico
Xipamanine
Count
0
5
10
15
1
2
3
4
5
Income Category