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Assessment of the Potential Adoption of Liquified Petroleum Gas for Cooking in Urban Households and Institutions of Malawi

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Abstract: More than 96% of Malawians relied on wood fuels for cooking and heating in 2018. About 4 million people now use charcoal for cooking in urban areas; resulting in environmental degradation, loss of forests resulting in increased run off, siltation of rivers and depletion of water resources in lakes and rivers in Malawi. This study assessed the potential adoption of Liquefied Petroleum Gas (LPG) as an alternative fuel to charcoal and firewood. A total of 1200 households in three cities were interviewed. Laboratory tests showed LPG as the most efficient cooking fuel tested among electricity, charcoal and firewood. Thermal efficiencies were recorded as LPG 68.1%, electricity 56.2%, Improved Firewood Stove 25.3%, and Improved Charcoal Stove 23.2%. Surveys conducted found that institutions used multiple cooking fuels depending on factors such as availability and cost. While electricity was the most preferred cooking fuel by institutions (54.5%), LPG was reported as back-up fuel for 100% of the institutions surveyed. LPG is perceived as an affordable fuel option by 26.3% of the institutions surveyed. At the household level, LPG-users reported benefits of efficiency (39%); reliability (37%) and cleanliness (27%). While the majority of high-income urban households use electricity for cooking, the majority of low- and medium-income urban households use charcoal for cooking. These results encourage increased investment in development of a nationwide LPG distribution network in Malawi.

Keywords: Cook Stoves, Efficiency, Households, Liquefied Petroleum Gas, Wood Fuels

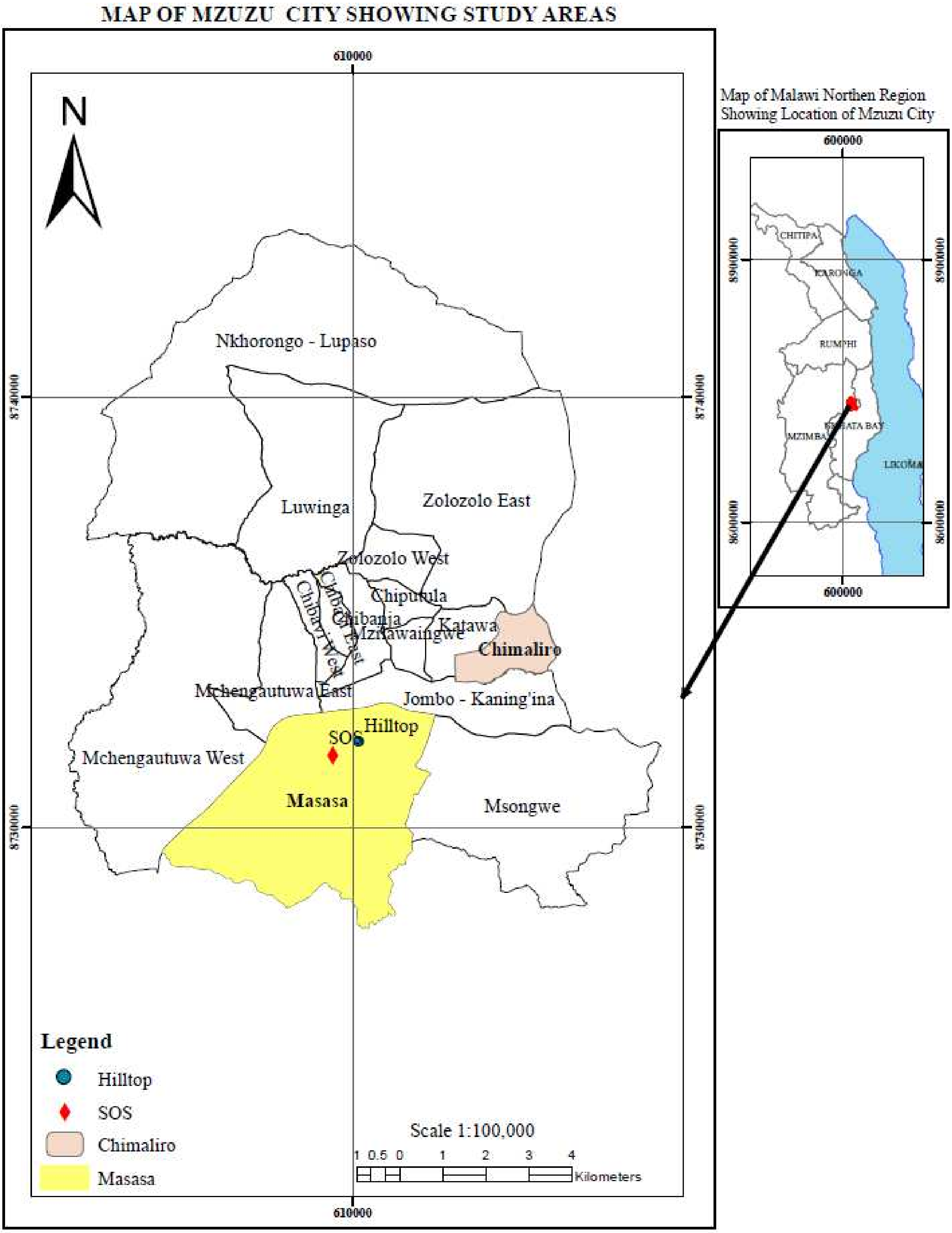
1. Introduction

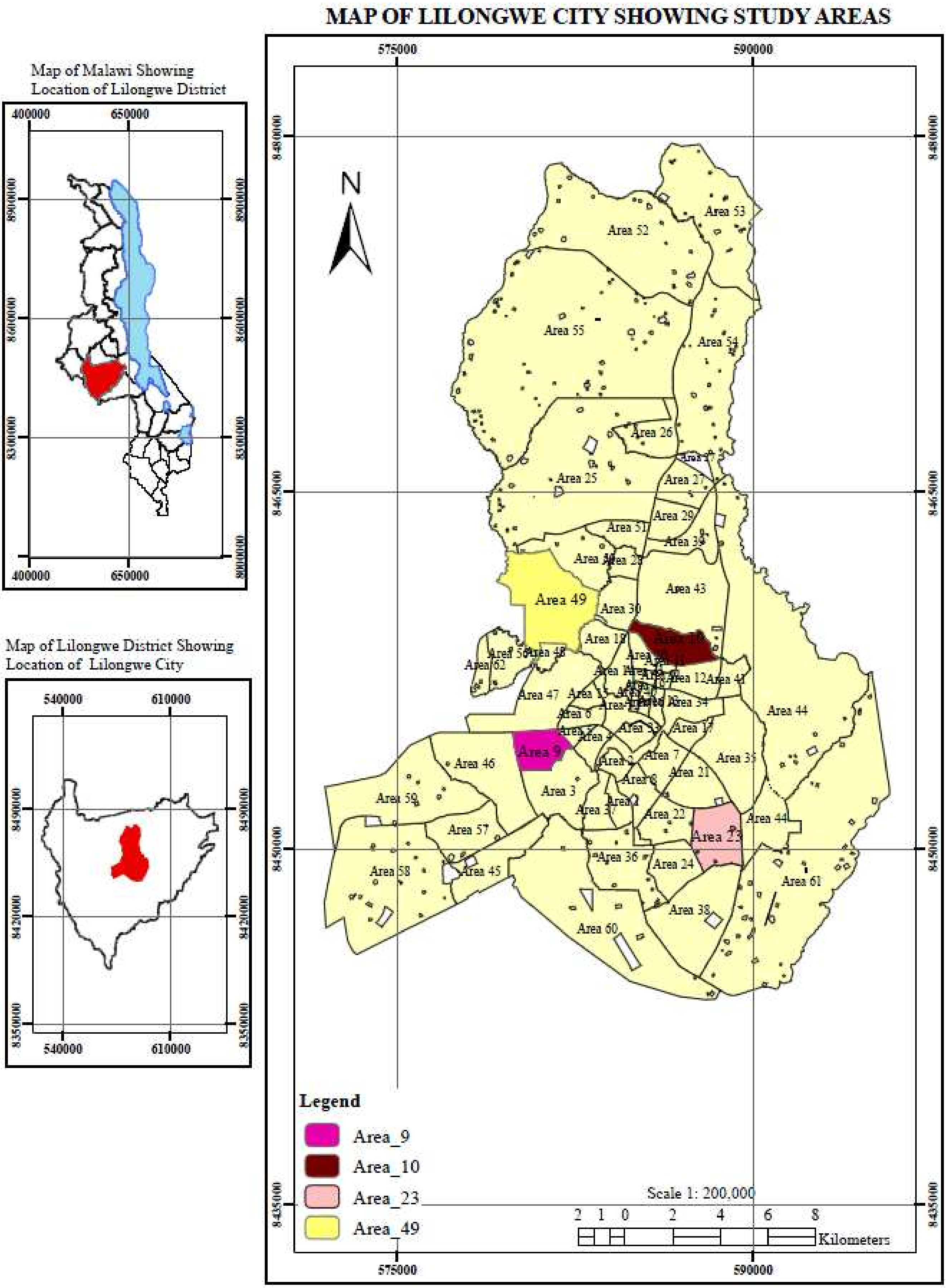
Energy poverty is a stark problem in most developing countries [8]. While efforts by most developing countries are at electrification in urban areas and grid extension in rural areas are expected to bring down the number of people who do not have access to electricity [12], the number of people using biomass for cooking is very high in most urban and rural households. The growth in electricity generation capacity has lagged behind the growth in electricity demand for a long period. Around 90% of Malawi's 18 million people [4] are not connected to the national electricity grid [2] and rely on dry cells, candles to light their homes and diesel for processing. Access to electricity (% of population) in Malawi was reported at 10% in 2016, according to the World Bank collection of development indicators, compiled from officially recognied sources. In rural communities only 5% is electrified which means the majority of Malawians are still in darkness [12].

Almost every Malawian household—more than 97% of the population—relies on firewood or charcoal (biomass energy) to meet their household cooking fuel needs [3]. Further, charcoal production improves livelihood in communities; however, if not controlled adverse effects will occur to the environment [5]. While firewood remains the most widely used cooking fuel in Malawi (87.7% in 2014), the percentage of Malawian's using charcoal as their primary cooking fuel grew significantly from 2% in 1998 to 11.3% in 2014 [3]. Growth in charcoal consumption is greatest in urban areas where more than 54% of residents reported charcoal as their primary cooking fuel in 2014.

With an annual population growth rate of 2.8% and urbanization rate of 4.2%, future demand for biomass energy is projected to outstrip supply by 2020.

The study also conducted laboratory tests to assess the performance metrics of Illegal and legal charcoals as cooking fuels; the performance of two firewood cook-stoves (Chitetezo Mbaula and 3-stone fire) and two charcoal burners (Environ-fit and Ceramic Jiko); and the performance metrics and cost of utilizing firewood, charcoal, electricity, and LPG as cooking fuels. The adoption of alternative cooking fuels [11] such as LPG will provide households with alternative cooking sources otherwise the continued reliability on charcoal will lead to loss of forests cover which will impact Malawians in multiple ways.




MAP OF LILONGWE CITY SHOWING STUDY AREAS
Map of Malawi Showing Location of Lilongwe District
Map of Lilongwe District Showing Location of Lilongwe City
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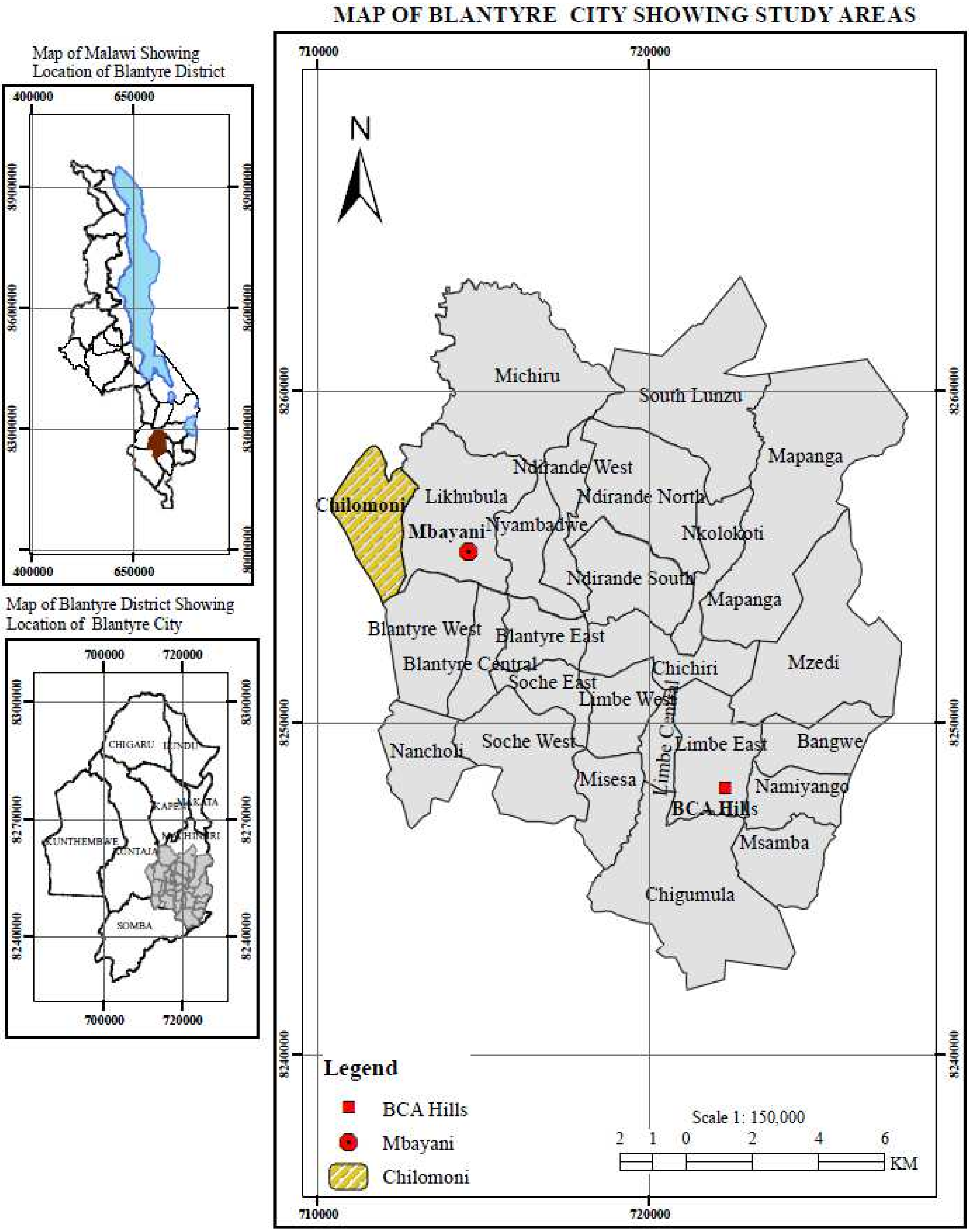

Figure 1. Maps of the Study Area.

Table 1. *Formula used in Calculating Sample size in each City, where the margin of error (e) is 0.05.*

CATEGORY	CITY	TOTAL POPULATION (N)	SAMPLE SIZE
Households	Lilongwe	N	$N / (1+Ne^2)$.=230,265/(1+230,265 $(e)^2$)=400
Households	Blantyre	N	$N / (1+Ne^2)$.= 191,676/1+191,676 $(e)^2$~400
Households	Mzuzu	N	$N / (1+Ne^2)$.= 49,564 /1+49,564 $(e)^2$~400

2. Materials and Methods

2.1. Description of the Study Area

Data was collected in 3 major cities in Malawi in the northern region (Mzuzu), Central region (Lilongwe) and Southern region (Blantyre) as shown if Figure 1.

2.2. Study Design and Data Collection Methods

The study was focused in Malawi's major cities Mzuzu, Lilongwe, and Blantyre where charcoal is highly consumed. A stratified random sampling was employed to find a representative sample in households' categories. Data was corrected in major cities of Mzuzu, Lilongwe and Blantyre. The study created clusters of locations in areas, Slovins Formula (Table 1) was used to determine sample sizes in each city and random sampling was applied to select the area where survey instruments were administered as categorized in income area.

A total of 1200 households were interviewed. The study also conducted the efficiency of charcoal, firewood, electricity and LPG as cooking fuels.

2.3. Performance Metrics

The first objective assessed the efficiency of charcoal, firewood, electricity and LPG as cooking fuels in Malawi. The approach to this assignment was to conduct water boiling tests (WBT) on stoves heated by firewood, charcoal, LPG and electricity. The firewood used was pieces of wood from natural tree illegally called *masuku a ntchile* whereas illegal charcoal (produced from unknown tree) and legal charcoal were the charcoals used. On the other hand, Afrox LPG and grid electricity were the sources of LPG and electricity, respectively. For each cooking fuel, a WBT was conducted from which appropriate variables were measured and performance metrics calculated.

Furthermore, controlled cooking tests (CCT) were done for each cooking fuel from which the measured and calculated variables were used to validate results of WBT. The performance metrics that were used to compare the cook-stoves or cooking fuels were temperature-corrected time to boil (t_{bT}); thermal efficiency (η_T); and turndown ratio (TDR). The corresponding formulas were used to calculate these metrics as given in equations 1 to 3. The definitions of the notations used in the expressions are given e.

$$t_{bT} = \frac{\left[\frac{75t_b}{T_b - T_{wi}}\right]_c + \left[\frac{75t_b}{T_b - T_{wi}}\right]_h}{2} T_{bt} = \frac{\left[\frac{75t_b}{T_b - T_{wi}}\right]_c + \left[\frac{75t_b}{T_b - T_{wi}}\right]_h}{2} \quad (1)$$

$$n_T = \frac{(n_T)_c + (n_T)_h}{2} = \left\{ \frac{\left[\frac{m_w c_w (T_b - T_{wi}) + h_{fg} m_p}{f_m(LHV(1-\overline{mc}) - mc(c_w - (T_b - T_a) + h_{fg}) - m_c HV_c)}\right]_c + \left[\frac{m_w c_w (T_b - T_{wi}) + h_{fg} m_p}{f_m(LHV(1-\overline{mc}) - mc(c_w - (T_b - T_a) + h_{fg}) - m_c HV_c)}\right]_h}{2} \right\} \times 100\% \quad (2)$$

$$TDR = \frac{\overline{FP}_c}{\overline{FP}_s} = \frac{\left[F_m\left(\overline{LHV}(1-\overline{mc}) - \overline{mc}\left(c_w(T_b - T_a) + h_{fg}\right)\right)\right]_c}{\left[F_m\left(\overline{LHV}(1-\overline{mc}) - \overline{mc}\left(c_w(T_b - T_a) + h_{fg}\right)\right)\right]_s} \times \frac{t_s}{(t_b)_c} TDR = \frac{\overline{FP}_c}{\overline{FP}_s} = \frac{\left[F_m\left(\overline{LHV}(1-\overline{mc}) - \overline{mc}\left(c_w(T_b - T_a) + h_{fg}\right)\right)\right]_c}{\left[F_m\left(\overline{LHV}(1-\overline{mc}) - \overline{mc}\left(c_w(T_b - T_a) + h_{fg}\right)\right)\right]_s} \times \frac{t_s}{(t_b)_c} \quad (3)$$

The cost of energy used per WBT of 1.5 liters (MWK/WBT) or cost of energy used per 1kg of the local staple *nsima* (MWK/kg nsima) were used to measure the normalized cost of using a particular type of fuel. Equations 4 and 5 were correspondingly used to calculate MWK/WBT and MWK/kg nsima.

$$MWK/WBT = C_f \times Q_f \times \overline{EHV} \; MWK/WBT = C_f \times Q_f \times \overline{EHV} \quad (4)$$

$$MWK/kg\ nsima = \frac{C_f \times Q_f \times \overline{EHV}}{Mass\ of\ nsima\ cooked} \; MWK/kg\ nsima = \frac{C_f \times Q_f \times \overline{EHV}}{Mass\ of\ nsima\ cooked} \quad (5)$$

The WBTs were conducted following the protocol stipulated in The Global Alliance for Clean Cook stoves WBT (The Global Alliance for Clean Cook stoves, 2014). A complete WBT underwent 3 phases vis-à-vis high-power cold start, high-power hot start, and low-power simmering. For each fuel, three tests of WBT were conducted. However, CCT which involved cooking nsima (1kg water and 0.3kg maize flour) was done once for each fuel (firewood, illegal charcoal, legal charcoal, LPG, and electricity). Selected pictures taken during the tests can be seen in Appendix 1.

2.4. Data Collection

All temperatures required in the computations of equations 1-5 were measured by digital thermometer equipped with k-type thermocouple for temperature probing. The thermometer was accurate to 0.1°C.

All masses required in the computations of equations 1-5 were measured by digital weighing scales. For small masses, a 1kg capacity scale with 0.01g accuracy was used whereas for greater quantities, a 100kg capacity scale with 0.05kg accuracy was used.

The moisture content of firewood and charcoal were determined through pre-weighing of 100g samples, oven drying, and post weighing of the samples. The samples for firewood, Illegal charcoal and Legal charcoal were made in triplicates. Further, the heating values of all fuels were obtained from literature whereas as the unit cost of fuel was calculated based on market prices.

2.5. Data Analysis

T-Test at 95% confidence was used to check significant difference of the mean t_{bT}, η_T, *MWK/WBT* and *TDR* for chitezezo mbaula and 3-stone firewood stoves from which a better stove was selected for further comparison with charcoal burner, LPG, electric stove. Similarly, T-Tests at 95% confidence were used to check significant differences (in terms of t_{bT}, η_T, *MWK/WBT* and *TDR*) between ceramic Jiko and Environfit charcoal burners as well as between environfit stove when burning illegal charcoal and Legal charcoal.

A better charcoal burner with acceptable type of charcoal was selected for further comparison with LPG, firewood, and electric cook-stoves. The significant differences between the performance metrics (t_{bT}, η_T, and *TDR*) as well as cost metric (MWK/WBT and MWK/kg nsima) were checked using one factor ANOVA.

3. Results and Discussions

3.1. Controlled Laboratory Tests

3.1.1. Performance of Cooking Stoves

A WBT was conducted for both the Chitetezo Mbaula and three-stone fire which yielded mean values of t_{bT}, η_T, *MWK/WBT* and *TDR*. The T-test results showed no statistically significance differences in Thermal efficiency, cost and turn down ratio of chitetezo mbaula and 3-stone stove ($p < 0.05$), whereas no significance differences were observed in Temperature corrected time to boil ($p = 0.192$). This implies that the Chitetezo Mbaula burns firewood more efficiently than the three-stone fire and is, therefore, more cost effective as evidenced from a lower MWK/WBT. Nevertheless, a higher TDR for the three-stone fire indicates that cooking power (energy per unit of time) in a three-stone fire can be controlled more widely than in Chitetezo Mbaula. However, observation revealed that power is generally difficult to control in firewood stoves. Overall, the Chitetezo Mbaula outperformed the three-stone fire and was carried forward for further comparison with charcoal, LPG, and electric stoves.

Furthermore, tests were carried to compare charcoal-burning Jiko and Envirofit stoves. For these tests, the same charcoal, Kawandama Hills Charcoal, was used in both stove types. These WBT results show that t_{bT}, η_T, *MWK/WBT* and *TDR* significantly differ between the Jiko and Envirofit charcoal stoves as revealed by *t*- test. Water boils at least 21% faster when boiled on an Envirofit charcoal stove than a Jiko stove. Results also revealed that the Envirofit stove uses less charcoal and thus is more cost effective than the Jiko charcoal stove. These charcoal savings can partially be attributed to the reduced heat loss due to the Envirofit stove design. Additionally, the Envirofit stove offers a firepower (the average power output of the stove in Watts) controlling range twice as large as the Jiko. These results suggest that the Envirofit charcoal stove is more cost effective and efficient than the Jiko.

3.1.2. Comparative Performance of Local Charcoal and Kawandama Hills Plantation Charcoal

The controlled laboratory testing compared local charcoal to Kawandama Hills Plantation charcoal. Table 4 shows that local charcoal and Kawandama Hills Plantation Charcoal are different in their burning characteristics. While both charcoals yielded statistically similar times to boil water, the local charcoal was found to have a higher thermal efficiency. On the other hand, the Kawandama Hills Charcoal proved to be superior in terms of firepower control.

Kawandama Hills Charcoal is more expensive than local charcoal. Kawandama Hills Plantation Charcoal may be more appealing to Malawians when this charcoal's retail price becomes more comparable to local charcoal. However, consumers who value time to boil over thermal efficiency may also prefer Kawandama Hills Charcoal to local charcoal or vice versa.

Table 2. *Water Boiling Tests.*

	Units	Local Charcoal			KHP Charcoal			Statistics	
		Mean	*SD*	*COV*	*Mean*	*SD*	*Cov*	*T-Test P Value*	*Significant with 95% Confidence*
Temperature corrected time to boil	Min	15.8	0.5	3.2%	15.1	0.6	3.9%	0.283	YES
Thermal efficiency	%	26.6	1.3	4.7%	23.2	1.3	5.5%	0.053	YES
Cost per WBT of 1.5 Litres	MWK/WBT	30.6	1.2	4.0%	52.7	2.1	4.0.%	8E-04	YES
Turndown ratio		1.2	0.2	16.9%	1.94	0.2	12.2%	0.029	YES

3.1.3. Comparative Thermal and Efficiency Tests of Cooking Appliances

A one factor ANOVA was done to compare all cooking appliances in the study. The one factor ANOVA showed that during WBT the t_{bT}, η_T, *MWK/WBT* and *TDR* significantly differ among the Chitetezo Mbaula, Envirofit stove (tested with Kawandama Hills Plantation Charcoal), LPG gas stove, and the electric hotplate. With reference to Figure 7, the findings of the study show that an LPG gas stove, electric hotplate, Chitetezo Mbaula, and Envirofit stove burning Kawandama Hills Plantation Charcoal are in the order of the most to least thermal efficient stoves. This is validated by results of the CCTs which show that an LPG gas stove, electric stove, Chitetezo Mbaula, and Envirofit stove burning Kawandama Hills Plantation Charcoal are in the order of the least to most energy consumed for a similar task. This data suggests that LPG cooking fuel conserves the most energy. This data also suggests that all firewood and charcoal stoves are highly inefficient and wasteful in terms of energy.

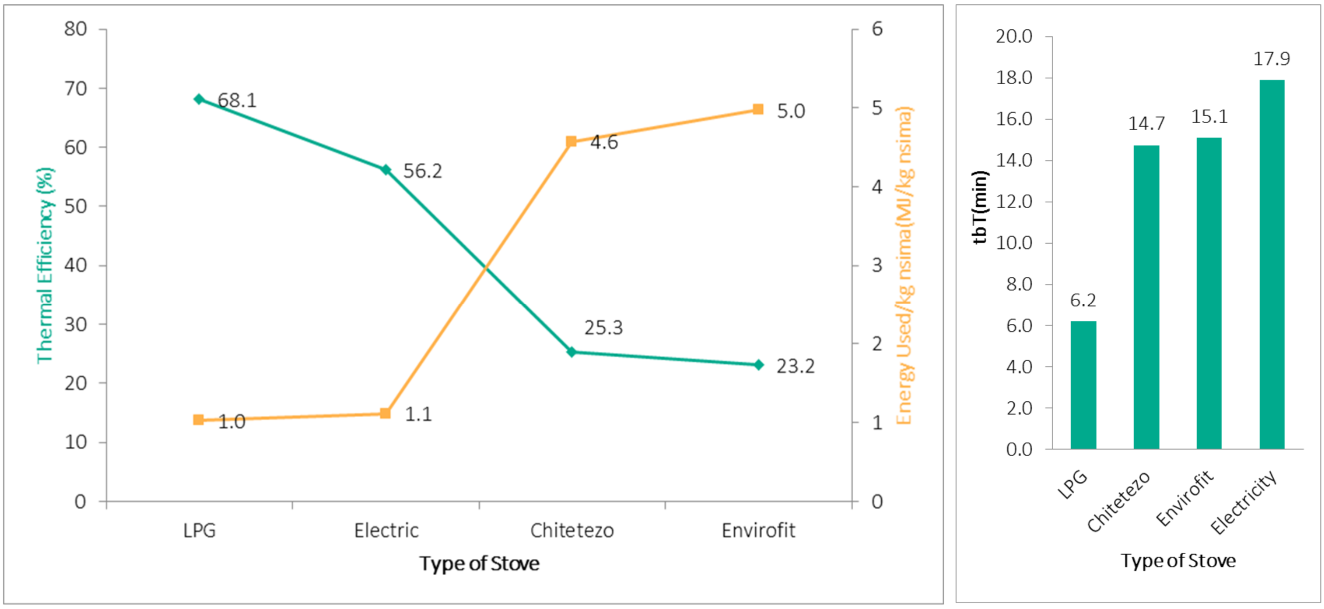

Figure 2. *Thermal efficiencies and energy use of different stoves and the effectiveness of different stoves.*

Furthermore, LPG as a cooking fuel exceeded other fuel types in terms of cooking time. Figure 8 shows that LPG stoves cook twice as fast as the Chitetezo Mbaulas and thrice as fast as the electric hotplate. The Chitetezo Mbaula and Envirofit stoves had comparable cooking times, which were slightly lower than the cooking times of the electric stove. However, Table 3 shows that LPG, electric, Chitetezo Mbaula and Envirofit stoves operated at different firepowers which, in turn, influences each stove's cooking time. Therefore, comparing cooking times of cooking appliances at the same fire power still favours the LPG stove over the electric hotplate (Table 3).

Table 3. *Firepower and Temperature Corrected Time to Boil during Hot Start Phase for All Cooking Appliances.*

	Hot Start Firepower (KW)	Hot start Temperature Corrected Time to Boil (min)	Temperature Corrected Time to Boil at 2.2 kW Firepower (min)
Chitetezo Mbaula	3.0	12.7	17.4
Three-Stone Fire	6.8	17.0	52.0
Envirofit (LC	2.5	10.7	12.1
Envirofit (KC)	2.8	11.9	15.1
Ceramic Jiko (LC)	2.2	21.5	21.6
Ceramic Jiko (KC)	2.4	21.0	22.8
LPG Stove	2.2	6.3	6.3
Electric Stove	1.0	18.8	8.3

Data in Figure 2 coupled with the data presented in Table 3 suggest that thermal efficiency and firepower strongly influence cooking time. From the domestic stoves tested, the LPG stove exhibits a better combination of thermal efficiency and firepower making it time effective compared to the rest of the appliances and fuels. Additionally, LPG exhibits a better turndown ratio than the rest of the fuels and stoves (Figure 3). This implies that for a LPG stove, power can be controlled over a wider range than for firewood, charcoal or electricity. Moreover, the power control mechanism is relatively easier to control in LPG and electric hotplates because this control simply involves adjusting a power control knob.

Although the Envirofit stove has a wider power range than the electric hotplate, the power control mechanism is cumbersome and involves removing charcoal from or adding charcoal to the burner in order to attain the desired power level. Sustaining a desired power level is also difficult to achieve with the Envirofit.

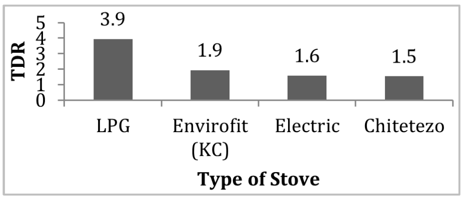

Figure 3. *Comparison of turndown ratios of different stoves.*

Although LPG as a cooking fuel outperforms firewood, charcoal, and electricity in terms of thermal efficiency, cooking time and turndown ratio, evaluations of equations 4 and 5 show that utilization of LPG gas in domestic cooking is currently the most expensive way of cooking in Malawi (Figure 10). From Figure 10, the cost of conducting a WBT and CCT yielded agreeable cost trends among the tested stoves. Cooking using firewood burned in a Chitetezo

Mbaula, electricity through a 1kW electric hotplate, Kawandama Hills Plantation Charcoal burned in an Envirofit stove, LPG in an LPG stove are in that order from the least to most expensive methods of cooking in Malawi. However, if time of cooking were converted to a monetary value, the cost of using LPG as cooking fuel would be reduced. Photos of the stoves and cooking appliances used are attached in appendices.

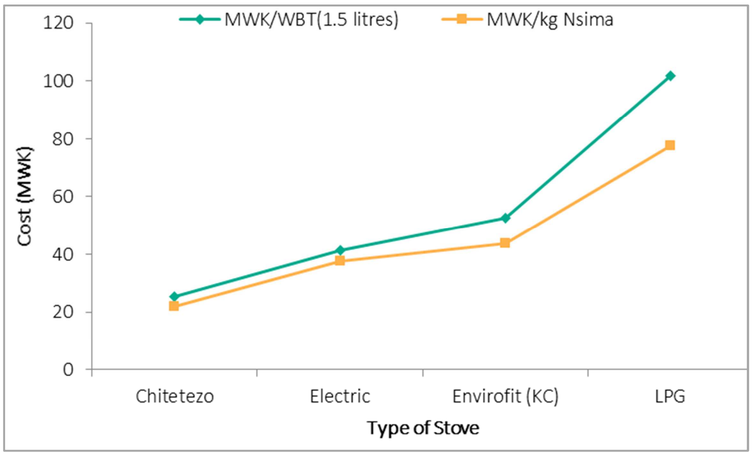

Figure 4. *Cost effectiveness of firewood in a chitetezo Mbaula, Electricity, Kawandama hills Plantation Charcoal in an Envirofit and LPG Stoves.*

Table 4. *Fuel Cost Calculations and fuel costs at Time of Study.*

Fuel Cost Calculations				
Fuel	**LHV (kJ/kg)**	**LHV (kWh/kg)**	**Quantity Bought (kg)**	**Amount (MWK)**
Firewood	18414	5.12	30.1	2100
Local Charcoal	29800	8.28	36.8	5000
Kawandama Hills Plantation Charcoal	29500	8.19	15.4	3500
LPG	44700	12.42	6	15500

Table 5. *Fuel Costs.*

Fuel	**MWK/KG**	**MWK/kWh**
Firewood	69.77	13.64
Local Charcoal	135.87	16.41
Kawandama Hills Plantation Charcoal	227.27	27.73
LPG	2583.33	208.05
Electricity	-	78.50

All the stoves used in the controlled laboratory tests had similar greenhouse gas emission outputs except for the LPG stove which did not emit CO. The LPG stove also emitted less CO_2, NO_2 and SO_2. The low emissions of LPG stoves were generally below the WHO interim $PM_{2.5}$ emissions target of (1.75 mg/min) were also. established in the study conducted by Johnston et al. (2019). The Envirofit stove emitted less SO_2 when burning the Kawandama Hills Plantation Charcoal than when burning local charcoal. Results are shown in Table 6 below. The research suggests further study to determine if the process of production of Kawandama Hills Plantation Charcoal has an effect on the level of emissions produced at cooking.

Table 6. *Fuel emission test results.*

Fuel	**CO_2 (ppm)**	**NO_2 (ppm)**	**SO_2 (ppm)**
Three-Stone Fire	0.4	0.8	14
Chitetezo Mbaula	0.4	0.8	22
Jiko (KC)	0.4	0.9	86
Jiko (LC)	0.4	0.9	121
Envirofit (LC)	0.4	0.9	86
Envirofit (KC)	0.4	0.9	43
Gas (LPG)	0.3	0.7	4

The values for Carbon Monoxide (CO) recorded by gas detectors varied with the vertical distance between the detector and the stove as seen in Table 7 below. With larger distances between the stove and the detector, higher emissions were recorded. Overall, firewood emitted more CO than charcoal and the LPG stove and electric hotplate emitted no CO emissions.

Table 7. *Carbon Monoxide Emissions Test Results.*

Stove and Fuel Type	**At 30 cm (ppm)**	**At 60 cm (ppm)**	**At 1 m (ppm)**	**At 2 m (ppm)**
Chitetezo Mbaula (Firewood)	690	133	19	19
Three-Stone Fire (Firewood)	160	113	56	24
Jiko (KC)	540	360	310	116
Jiko (LC)	585	210	177	60
Envirofit (LC)	630	260	210	103
Envirofit (KC)	82	73	72	61
Gas (LPG)	0	0	0	0
Hotplate (Electricity)	0	0	0	0

Table 8. *Demographic characteristics.*

Demographic Variable	Descriptive Statistics				
	General Sampled Population	High Income Urban Areas	Middle Income Urban Areas	Low Income Urban Areas	Rural Areas Impact Areas)
Proportion of Male Respondents	29%	23%	34%	21%	30%
Proportion of Female Respondents	71%	77%	66%	79%	70%
Average Age of Respondents	38	40	36	35	38
Proportion with No Education	6%	2%	0%	0%	7%
Proportion with Primary Education	55%	4%	0%	24%	63%
Proportion with Secondary Education	24%	15%	32%	57%	22%
Proportion with Tertiary Education	15%	79%	68%	19%	7%
Average Household Income (MK)	142,923	1,094,411	351,105	114,846	59,006
Average Household Expenditure (MK)	78,636	610,257	186,960	83,916	30,385

The household data collected in urban areas revealed twenty-nine percent (29%) of those interviewed were male while 71% were female. Six percent of the household heads had no education, 55% had primary education, 24% secondary education and 15% tertiary education. An average household earned MK142, 923 a month. Adjusting this for the household size, which averaged 5 in our sample, the per capita income averaged MK34, 051. Therefore, the study largely dealt with low income households who were mostly female. Using the NSO poverty line of MK37, 002 the average household included in the study was poor. The statistics described above are useful for setting a general context of the sample used in the study.

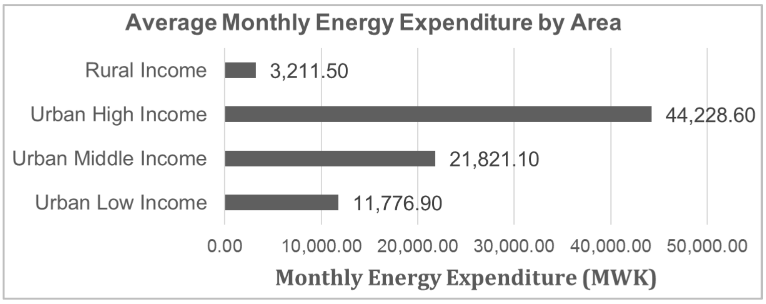

Figure 5. *Average Monthly Energy Expenditure by Area.*

3.2. Household Surveys

3.2.1. Average Household Expenditure of Cooking Fuels

The study found that urban households spend on average MWK 25,942 per month on cooking fuel while rural households reported that they spend only MWK 3,211 per month on cooking fuel. A paper by ("Dynamics of Household-level Energy Access in Vietnam during 2002-2014," 2019) depicts the urban households spend more on energy due to their high-income status. This wass also backed by [10] who identified income status as the main reason for higher energy expenses in urban households. Lower energy expenses in rural areas is explained by the fact that surveyed households collect fuel wood for free from their fields and the surrounding forests. Figure 6 shows the average household energy expenditure by area.

3.2.2. Choice of Cooking Fuels

In most households interviewed, fuel stacking was observed, consistent with findings throughout SSA13 [7]. Fuel stacking can be understood as the use of multiple cooking fuels used in a household. This was especially common in urban areas, but was also seen in rural areas. While studies have evaluated specific interventions and assessed fuel-switching in repeated cross-sectional surveys at household level, the role of different multilevel factors in household fuel choice, across diverse community settings, is not well understood [9].

Respondents were asked to rank the four fuel types of electricity, LPG, firewood and charcoal in order of their preference. The number one preference of all households was then disaggregated by area of residence and by urban income level as shown in the figures below. In rural areas, firewood was reported to be the most preferred cooking fuel by 90.6% of rural surveyed. This result is not only in Malawi but also in other countries. It has been noted that that firewood use has remained the most used fuel for more than 40 years in Africa and other continents [7]. The next preferred cooking fuel was charcoal by 8.8% of rural households. In urban areas, electricity was reported as the most preferred cooking fuel by 54% of urban households. Behind electricity, charcoal was the second most preferred cooking fuel with 34% of households choosing this fuel as their preferred cooking fuel. This was followed by LPG, a preference for only 12.1% of urban households. The least preferred cooking fuel was firewood (1.9%). According to ("Dynamics of Household-level Energy Access in Vietnam during 2002-2014," 2019) suggests the level of education of the head of the household is clearly related to household fuel choice. This is, of course, in part, because higher education levels in a family translates into higher incomes and expenditure levels for these households. This s not surprising as major cities of Malawi (i.e., Blantyre, Lilongwe, and Mzuzu) recorded higher levels of energy expenditure.

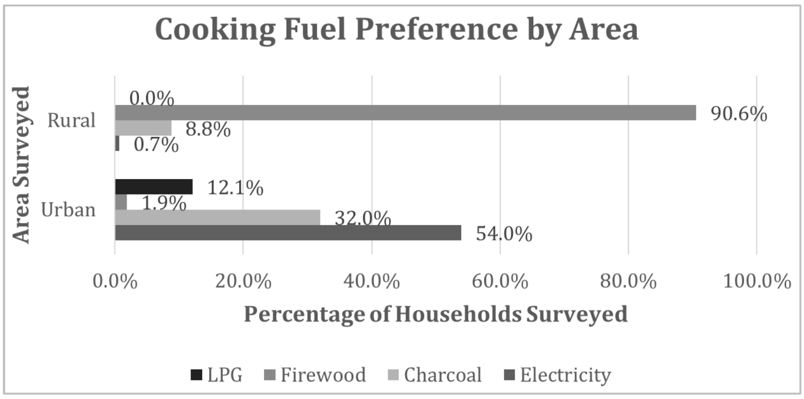

Figure 6. *Household Cooking Fuel Preference by area.*

When the cooking fuel preference was disaggregated by urban income level, the preferred cooking fuel between income levels varied. For high income households, electricity was the preferred cooking fuel (72.1%), but in middle and low income households charcoal was the preferred cooking fuel at 53.3% and 80.0%, respectively. [6] reported that the household fuel preference is highly decided through main factors however income players a major role in the choice of fuel at household level. The hgh income preference of cooking electricity is associated with high income levels as are able to afford cooking on electricity. LPG was reported as the preferred cooking fuels for 0% of rural households, but 12.1% of urban households prefer this cooking fuel. When analyzing LPG preference among the urban income levels, LPG was the second-most preferred cooking fuel for high income households at (15.7%), but ranked as the 3rd most preferred cooking fuel for middle and low income households only ahead of firewood.

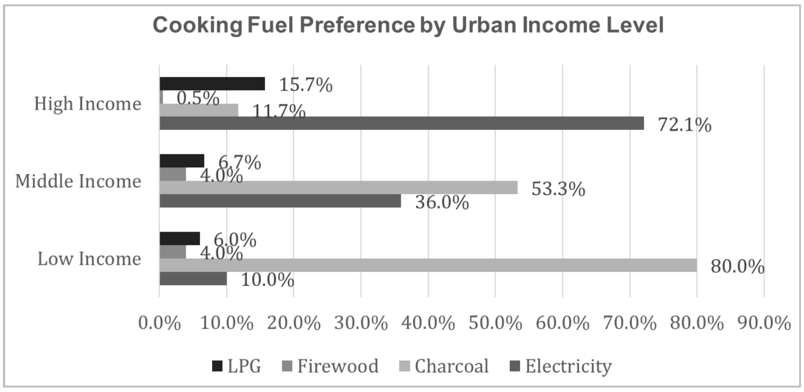

Figure 7. *Urban Household Cooking Fuel Preference by Income Level.*

The survey collected urban respondents' rationale behind their top cooking fuel preference. Table 4 displays that whether or not a cooking fuel is locally available is the overall the main reason behind household cooking fuel preference. For both charcoal and firewood, households' main rationale for choosing these cooking fuels was the fuel's perceived affordability. For those who prefer LPG, the number one reason given behind their preference was that LPG cooks faster.

Table 9. *Reason for Preferred Cooking Fuel.*

	Locally available (%)	Affordable (%)	Safe (%)	Clean (%)	Fast (%)
Electricity	21.7	42.2	3.6	5.5	27.1
LPG	5.3	18.4	0.0	15.8	60.5
Charcoal	52.5	33.3	0.0	3.0	11.1
Firewood	50.0	33.3	0.0	0.0	16.7

In the market assessment survey of 300 households, a question on cooking fuel affordability was also asked. In this survey, households were categorized according to their most preferred cooking fuel and then asked if they considered their most preferred cooking to be the most affordable among the alternatives. Results are presented below.

Table 10. *Household Perception on Cooking Fuel Affordability.*

Cooking Fuel	% Households
Electricity	42%
Firewood	33%
Charcoal	32%
LPG	18%

Among households that prefer using electricity, 42% rated it as the most affordable cooking fuel. Similarly, of those who prefer using firewood, charcoal and LPG, 33%, 32% and 18%, respectively also consider their preferred cooking fuel type the most affordable option available to them. Therefore, electricity is considered the most affordable cooking fuel while LPG is perceived the most expensive. Lack of affordability imposes a significant market barrier to LPG [1]. Households use a mix of energy sources rather than one particular source. Households interviewed primarily choose a particular fuel due to factors such as cost of the fuel, time taken to cook a meal, availability of the fuel in the area, cleanliness of the fuel, and ease of use. Hence the household preference fuel is jeopardized considering such factors.

3.2.3. Cooking Appliances

The study confirmed that the most common type of cooking appliance used in rural and urban areas was dictated by the most common fuel available in that particular area. For rural areas, the most commonly available fuel is firewood; therefore, the majority of rural respondent's report using a three-stone fire (68%) to cook. In rural areas, improved firewood cook stoves were also used by 23.5%. Improved cookstoves observed were the Chitetezo Mbaula, the TLC Rocket Stove, mudded cookstoves, and metal firewood stoves. In urban areas, where the most available fuels are charcoal and electricity, the majority of low-income respondents reported using a charcoal stove, specifically the Jiko (88%), while the majority of middle-income households (55%) and high-income households (72%) reported using an electric cooker. The figures below illustrate the choice of cooking appliance by location and, for urban respondents, income level.

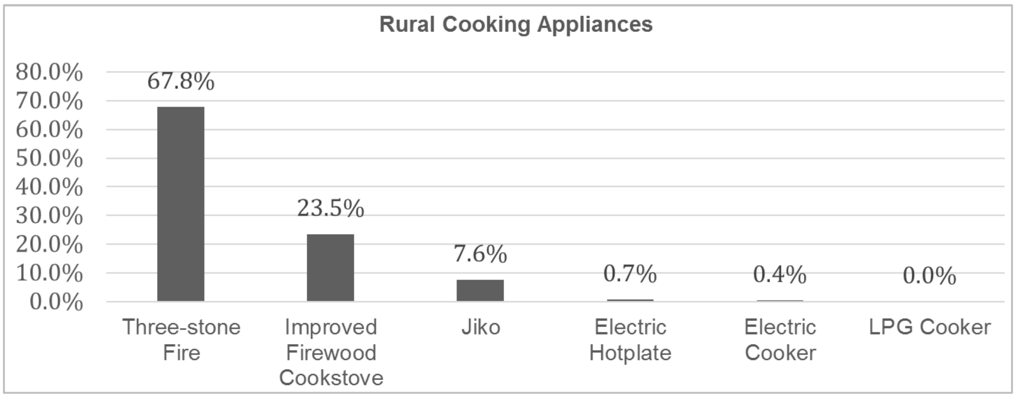

Figure 1. *Rural household cooking appliances.*

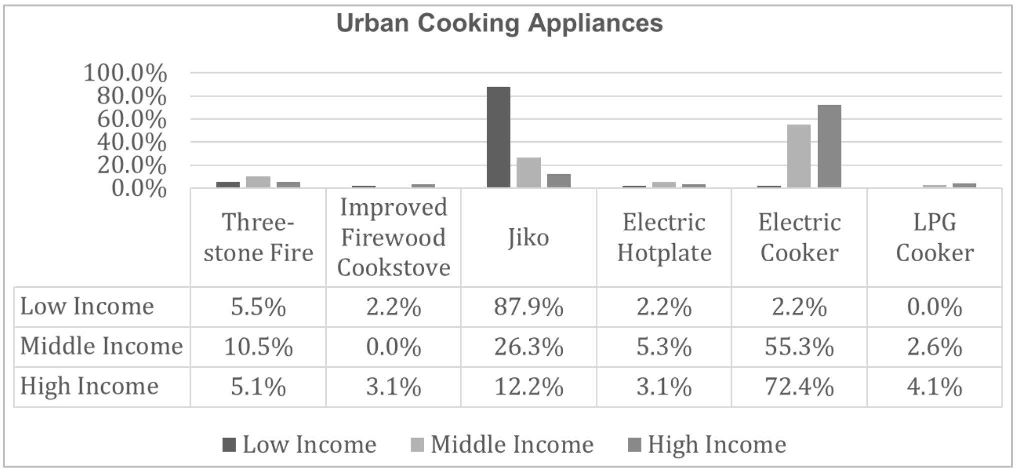

Figure 9. *Urban Household Cooking Appliances.*

3.2.4. Gender and Cooking

The household survey also asked respondents to report which gender within their household cooks. Results disaggregated by area of residence are presented in Figure 10 below. The results show that cooking in rural households and urban households is predominantly done by girls and women. While data shows that women and girls are primarily responsible for household cooking, it does not suggest that this gender is responsible for household cooking fuel or appliance decisions.

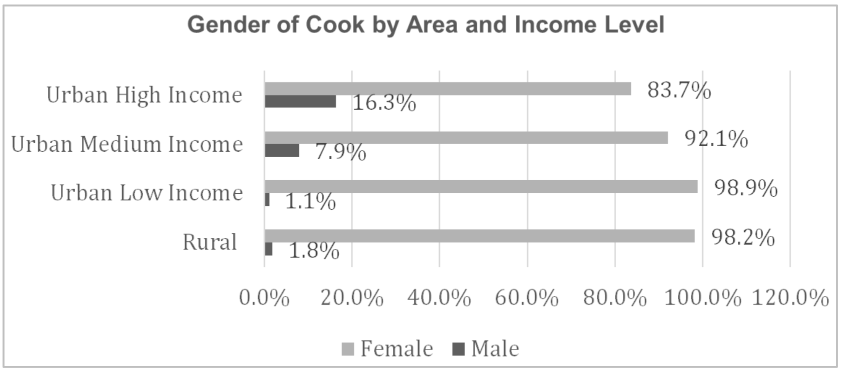

Figure 2. *Gender of Household Cook by Area and Income Level.*

4. Conclusions and Recommendations

1. LPG is a more efficient cooking fuel when compared to other common fuels used in Malawi, with low adoption in Malawi due to inadequate knowledge on its efficiency, safety and cost.
2. While the costs of charcoal and electricity have increased in recent years, LPG prices have been nearly consistent. Therefore, the researcher feels LPG is a cost-competitive cooking fuel for most households and institutions.
3. The research has found that there is potential for growth for the LPG sector in Malawi. The current low supply and underdeveloped distribution network has resulted in higher transactional costs for distributers and higher retail prices for consumers. Therefore, the research recommends that the private sector should increase investment in a nationwide distribution network for LPG.
4. The research found there is inadequate knowledge about LPG cooking fuel efficiency and cost. In addition, there is a general public perception that LPG is unsafe to use. The researcher recommends the need for increasing awareness of LPG benefits as a cooking fuel. Key awareness messages should focus on the efficiency and safety of LPG as a cooking fuel and offer assurance to new users to adopt the fuel and increase use by existing users, who currently only use LPG as a backup fuel to electricity.

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Appendix: Pictures Taken During the Study

Figure 11. *Test rig during WBT for ceramic jiko burning local charcoal. Digital thermal and k-type thermocouple probed into the water are shown.*

Figure 12. *A weighing scale used during the tests for measuring bigger mass quantities.*

Figure 13. *Controlled cooking test for chitetezo mbaula and 3-stone fire.*

Figure 14. *Stoves from left to right: Environfit, LPG stove, ceramic Jiko. Bags of charcoal from right to left: Kawandama, local.*

References

[1] Dalaba, M., Alirigia, R., Mesenbring, E., Coffey, E., Brown, Z., Hannigan, M., Wiedinmyer, C., Oduro, A., & Dickinson, K. L. (2018). Liquified Petroleum Gas (LPG) Supply and Demand for Cooking in Northern Ghana. *EcoHealth*, *15* (4), 716–728. https://doi.org/10.1007/s10393-018-1351-4

[2] ESCOM. (2016). *ESCOM Annual Financial Statement 2016.pdf*. Electricity Supply Corporation of Malawi.

[3] NSO. (2015). *Malawi MDG Endline Survey 2014: Monitoring the situation of children and women*.

[4] NSO. (2018). *MALAWI POPULATION AND HOUSING CENSUS REPORT-2018 2018 Malawi Population and Housing Main Report* (Issue May). http://www.nsomalawi.mw/images/stories/data_on_line/demography/census_2018/2018 Malawi Population and Housing Census Main Report.pdf

[5] Rayos, A. H. (2017). LPG Industry Regulatory Framework (Household LPG) and Gasoline Station Training and Loan Fund. *Energy Consumers and Stakeholders Conference*, *November*.

[6] Semenya, K., & Machete, F. (2019). Factors that influence firewood use among electrified Bapedi households of Senwabarwana Villages, South Africa. *African Journal of Science, Technology, Innovation and Development*, *11* (6), 719–729. https://doi.org/10.1080/20421338.2019.1572336

[7] Serrano-Medrano, M., Ghilardi, A., & Masera, O. (2019). Fuelwood use patterns in Rural Mexico: A critique to the conventional energy transition model. *Historia Agraria*, *77*, 81–104. https://doi.org/10.26882/histagrar.077e04s

[8] Sharma, U. C. (2019). *ROLE OF ENERGY IN BRIDGING THE RURAL – URBAN GAP IN INDIA*. *March*.

[9] Shupler, M., Hystad, P., Gustafson, P., Rangarajan, S., Mushtaha, M., Jayachitra, K. G., Mony, P., Mohan, D., Kumar, P., P V M, L., Sagar, V., Gupta, R., Mohan, I., Nair, S., Varma, R. P., Wei, L., Hu, B., You, K., Ncube, T., … Brauer, M. (2019). Household, community, sub-national and country-level predictors of primary cooking fuel switching in nine countries from the PURE Study. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/ab2d46

[10] Uhunamure, S. E., Nethengwe, N. S., & Tinarwo, D. (2019). Correlating the factors influencing household decisions on adoption and utilisation of biogas technology in South Africa. *Renewable and Sustainable Energy Reviews*, *107* (November 2018), 264–273. https://doi.org/10.1016/j.rser.2019.03.006

[11] Van Leeuwen, R., Evans, A., & Hyseni, B. (2017). *Increasing the Use of Liquefied Petroleum Gas in Cooking in Developing Countries*. Livewire.

[12] Widijantoro, J., & Windarti, Y. (2019). Fostering clean and healthy energy in rural communities: Lessons from the Indonesia clean stove initiative pilot program. *International Journal of Energy Economics and Policy*, *9* (1), 107–114. https://doi.org/10.32479/ijeep.7085