FINAL QUANTITATIVE REPORT ON THE COST AND EFFICIENCY OF COOKING FUELS IN MALAWI

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EXECUTIVE SUMMARY

The study has investigated the cost and efficiency of four cooking fuels (electricity, LPG, firewood and charcoal) using household surveys and laboratory experiments. Household surveys were conducted in rural (PERFORM impact areas) and urban areas. A sample of 1,500 households (1200 rural; 300 urban) were interviewed during household surveys and five laboratory tests (water boiling; fuel consumption; fire power; thermal efficiency and; emissions test) were conducted.

Household surveys found that Firewood is the main cooking fuel in rural areas of Malawi. Low income urban areas across all four main cities of Malawi prefer using charcoal while middle and high income areas are more likely to use electricity for cooking. The study has confirmed low uptake of LPG as a cooking fuel with only 2% of the urban population monitored using the fuel and 0.35% of the total population studied use the fuel for cooking. Time and cost analysis of the four cooking fuels at household level revealed that LPG was the most efficient followed by Charcoal. The study has shown that Firewood is the cheapest source of cooking fuel and Electricity the most expensive. Regarding household expenditure on fuels, it was found that urban households spend on average MK25, 943 on cooking fuels compared to MK3, 211 for rural households. The researchers established that rural households usually source firewood from their fields and forest reserves hence the low level of expenditure of fuels.

Out of five fuel efficiency tests (water boiling; fuel consumption, fire power, thermal efficiency and emissions level) conducted in at laboratory setting for the four cooking fuels, LPG gas was found to be the most efficient fuel in terms of time, fuel consumption and level of emissions. A comparison test of cooking stoves showed that the Enviro fit Cook stove was more efficient than Ceramic Jiko. However, the amount of charcoal consumed was comparatively similar. The Chitetzo Mbaula (Firewood B) was more efficient than 3 stone-fire (Firewood A) when used with firewood. Firewood and Charcoal produced more CO than any other type of

This quantitative study has found that LPG is a comparatively cost efficient cooking fuel as shown by both household analysis and laboratory tests of the other cooking fuels available in Malawi. The study team therefore recommends that LPG should be promoted and given more attention by policy makers, private sector and individual households. In rural areas where firewood is main cooking fuel, more efficient stoves such as the Environ-fit stove should be promoted. Efforts to address rampant use of charcoal should be targeted at low income urban residents who should be empowered to efficiently use charcoal and adopt LPG as its alternative.

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List of Acronyms and Abbreviations

CO	Carbon Monoxide
CO_2	Carbon Dioxide
ESCOM	Electricity Supply Corporation of Malawi
GDP	Gross Domestic Product
GoM	Government of Malawi
IEA	International Energy Agency
kWh	Kilowatt-hour
LPG	Liquefied Petroleum Gas
MSB	Malawi Bureau of Standards
NCS	National Charcoal Strategy
NSO	National Statistical Office
PAC	Practical Action Consulting
PERFORM	Protecting Ecosystems and Restoring Forests in Malawi
SO2	Sulfur Dioxide
USAID	United States Agency for International Development
WBT	Water Boiling Test

1. INTRODUCTION

Practical Action Consulting is conducting a "Quantitative and Qualitative Market Research on Liquefied Petroleum Gas (LPG) in Malawi with grant funding from the the Protecting Ecosystems and Forests in Malawi (PERFORM) activity of the United States Agency for International Development (USAID Malawi). The project goal is to support National Charcoal Strategy (NCS) framework on increasing use of fuel-efficient cook stove technologies (to increase efficiency in consumption of biomass energy) in Malawi. The objective of this study was to document the comparative costs and efficiencies (in areas not limited to health effects/impacts and indoor pollution) of the four cooking fuels namely Charcoal, Firewood, Electricity and LPG

The study was designed as a quantitative social and scientific research on the cost and efficiency of LPG in comparison to three other cooking fuels (Charcoal, Firewood and Electricity). This report has been prepared to document the findings of household fuel energy surveys and laboratory experiments conducted by the study team. PAC study team conducted household surveys and laboratory experiments to measure the cost and efficiency of different cooking fuels. The Malawi Bureau of Standards (MBS) was contracted to conduct laboratory experiments measuring the efficiency of the fuels under comparison, including levels of emissions. MBS also conducted test to compare the efficiency of different cooking stoves. At household level, PAC identified 300 volunteer families living in urban areas (disaggregated as high income; middle income and low income) and documented their fuel energy use patterns and cost implications. In addition, a total of 1,200 households from communities targeted by the USAID Malawi - PERFORM activity were sampled and interviewed.

PAC recruited and trained a team of research assistants and supervisors who were deployed in both urban and rural areas to conduct the study. The research team monitored expenditure in energy relative to overall household expenditure, energy choices and, efficiency of the energy through recording of period taken to prepare family meals. Water Boiling Test (WBT) was conducted at a laboratory run by the Malawi Bureau of Standards. This is a simplified simulation of the cooking process intended to measure how efficiently fuel is used to heat water in a cooking pot and the quantity of emissions produced while cooking. During the WBT, the level of pollutants under each source of cooking fuels was measured. The study adopted basic testing protocol for measuring carbon monoxide (CO), and carbon dioxide (CO2) concentrations in the fumes released by each fuel.

This report has been structured in such a way that it focuses on discussing the methodology, results and recommendations related to the cost and efficiency of LPG in comparison with the other three cooking fuels (charcoal, firewood and electricity) under investigation. The study methodology used for conducting household fuel energy surveys and efficiency tests at laboratory level are discussed in Section 2 of the report. Section 3 is a summary and discussion of key findings from the study followed by Section 4 which is a conclusion of the discussions. Section 5 has a list of recommendations that PAC has drawn from the results of this study. The report has a reference Section number 6. Finally, the study tools used at household level and during laboratory experiments are presented in Appendix Section 7.

2. STUDY METHODOLOGY

The study was conducted in two phases, the first phase involved household fuel use surveys conducted in rural (focusing on PERFORM targeted communities) and urban areas. The household surveys captured data on fuel use patterns and cost among rural and urban households. The second phase of the study involved conducting controlled laboratory experiments to measure the efficiency of the four cooking fuels.

2.1. Household Cooking Fuels Survey

2.1.1. Study Areas

Household surveys were conducted in PERFORM targeted communities surrounding Perekezi forest in Mzimba, Ntchisi forest reserve and Liwonde in Machinga districts. The study team selected urban households in Mzuzu, Lilongwe, Blantyre and Zomba. The energy consumption patterns of urban households were followed throughout a period of one week.

2.1.2. Household Sample Size and Sampling Framework

The study team applied random sampling framework to select a total of 1,200 households in the three rural communities. The team purposively classified urban communities into low, middle and high income areas. A total of 300 volunteer households were selected from these urban communities and their energy consumption patterns were monitored for a period of 1 week. Table 1 below shows the areas and number of households sampled.

Table 1: Sample size per study area

Study Area	Study Area Classification	Total Sample
Urban Areas (Mzuzu; Lilongwe; Blantyre and Zomba)	Low Income	100
	Middle Income	100
	High Income	100
Perekezi, Mzimba	Rural	400
Ntchisi Forest, Ntchisi	Rural	400
Liwonde, Machinga	Rural	400
Total Sample		1,500

2.1.3. Data Collection and Tools

Data collection was conducted using a structured questionnaire administered at household level by Research Assistants. In urban areas, an additional data collection form was used to collect fuel use data on a daily basis from volunteer households for a period of one-week. The study team used the following method in order to randomly select households interviewed: (a) determined the approximate geographic center of the selected cluster; (b) choose a random direction from the center (identified all possible directions, and selected the direction by spinning a bottle); (c) Randomly selected (using random number tables) a number between one and 9; (d) the number picked (for example 3) was the first house interviewed and subsequent households were selected after a count of the interval number selected. The research assistants were trained to correctly introduce themselves and the objective of the study. Consent from the respondent was secured before administration of the questionnaires.

2.1.4. Data Analysis and Quality Assurance

As part of ensuring quality of data, the training of enumerators was thoroughly done covering a wide range of issues. In addition, enumerators were advised to cross-check filled questionnaires before leaving each of the households and entities. The filled questionnaires were then checked by the supervisors for possible inconsistencies and incompleteness of data collected and appropriate remedial measures were taken. In the field, supervisors were also conducting spot checks on the selected households to verify the quality of data collected . Daily briefs were made to give feedback to all team members regarding progress of the study. In addition, before leaving each category, the field supervisors ensured that the correct number of clusters had been completed.

Data from instruments filled-in during data collection including supervisor's log was entered on to the computer using Microsoft Excel. Protocols for compiling cleaned data sets that are readily accessed, merged and exported were followed. This included, but not limited to: identifying and documenting missing data (incomplete information from households); eliminating redundant data observations (if data from the same household was entered more than once); ensuring that all components of data are correctly identified so as to ensure that data sets can be easily merged; ensuring that data reflects total sample size; completing inventory of database; completing electronic archiving of questionnaires and; computing tables, figures and statistics.

Data recorded in Microsoft Excel was exported and analysed in STATA package. This enabled the study team to summarize and organize the data to answer the research questions. Results of this analysis are presented in Section 3.

2.2. Fuel Efficiency Tests

The Malawi Bureau of Standards (MBS) was contracted to conduct the efficiency and emissions tests for the four cooking fuels namely LPG, Charcoal, Firewood and Electricity in a laboratory environment. The cold start high power Water Boiling Test (WBT) was used to assess the performance of the various types of appliances which included: an electric hot plate; Liquefied Petroleum Gas (LPG) burner; a Ceramic Jiko Stove; Enviro Fit Stove; 3-Stone (Fire wood A) and; Chitetezo mbaula (Firewood B). The following are the parameters that were measured:

a) Temperature, using a digital thermocouple thermometer;
b) Mass of the fuel before and after the test was measured, using a digital weighing scale;
c) Fuel Moisture Content. An oven was used to control moisture to the required levels from the fuel samples.
d) Time using a stopwatch
e) Electric power consumption was assessed using a power quality analyser.
f) Gaseous Emissions (CO, CO_2, NO_x, and SO_x) using Gas Detectors.

2.3. Limitations of the Study

During the study, some households withdrew in the course of daily energy consumption monitoring despite having earlier consented to the process. To address this challenge, the study team had increased the number of households under observation by 5 to cover those dropping out and inconsistencies in provision of data.

The study team experienced delay in receiving test results from the Malawi Bureau of Standards who were contracted to conduct laboratory tests on the four cooking fuels. The tests were expected to be conducted within 4 weeks; however, results were only received after 8 weeks hence leading to delay in competition of the milestone.

Furthermore, particulate matter tests were omitted from the study as there were no institutions in Malawi with capacity to undertake such experiments at the time of the study.

3. RESULTS AND DISCUSSION

This chapter presents the empirical results of the analysis of the data collected during the study using the methodology discussed in **Section 2** above. First, household fuel survey results are presented starting with the general descriptive socio-demographic statistics of the households under study. Second, results on the composition and sources of cooking fuels are presented, followed by on the determinants of choice of cooking fuels. Then, results on time-efficiency and costs of a variety of cooking fuels are discussed. Finally, the chapter presents laboratory results on efficiency and emissions tests conducted by the Malawi Bureau of Standards.

3.1. Household Fuel Surveys

3.1.1. Demographic Characteristics

Before we discuss the empirical results, we briefly discuss features that characterize our data. A number of socio-economic and other factors exert some degree of influence on the rate of fuel consumption and cost. Some of the major factors considered in this study are the number of people per households; average income level per household; education levels and; who does most of the cooking at in the household.

In the study, 16 % of the households were based in urban areas while 84% were based in rural areas. Twenty nine percent (29%) of those interviewed were male while 71% were female. Six percent (6%) 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 rural households who were mostly female with primary education. 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.

However these statistics mask marked variations among households from the various categories: low, middle, high income areas and rural areas (PERFORM impact communities). To underscore these variations, socio-demographic statistics disaggregated by area are presented in **Table 2** below:

Table 2: Demographic characteristics

Demographic Variable	Descriptive Statistics				
	General Sampled Population	High Income Urban Areas	Middle Income Urban Areas	Low Income Urban Areas	Rural Areas (PERFORM 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

3.1.2. Average household expenditure on fuels

Findings indicate a reasonably good prediction of household's expenditure variation according to the location of the household. Variations also existed with regard to monthly incomes and expenditures. The study found that on average, a household from high income areas earns MK1, 094, 411 and spends MK610, 257 per month. In the middle income areas, average household monthly incomes were recorded to be MK351, 105 and average expenditure was MK186, 961. On average, a household from low income areas has an income and expenditure of MK114, 846 and MK83, 916 respectively. Average monthly income from rural areas was recorded to be MK59, 006 with average expenditure of MK30, 385.

The study found that urban households spend on average MK25, 942 per month on cooking fuels while rural households reported that they spend only MK3, 211 per month on fuel energy. The low levels of energy expenses in rural areas is explained by the fact that surveyed households collect fuel wood for free from their fields and surrounding forests. The figure below shows proportion of income spent on fuel according to location of a household.

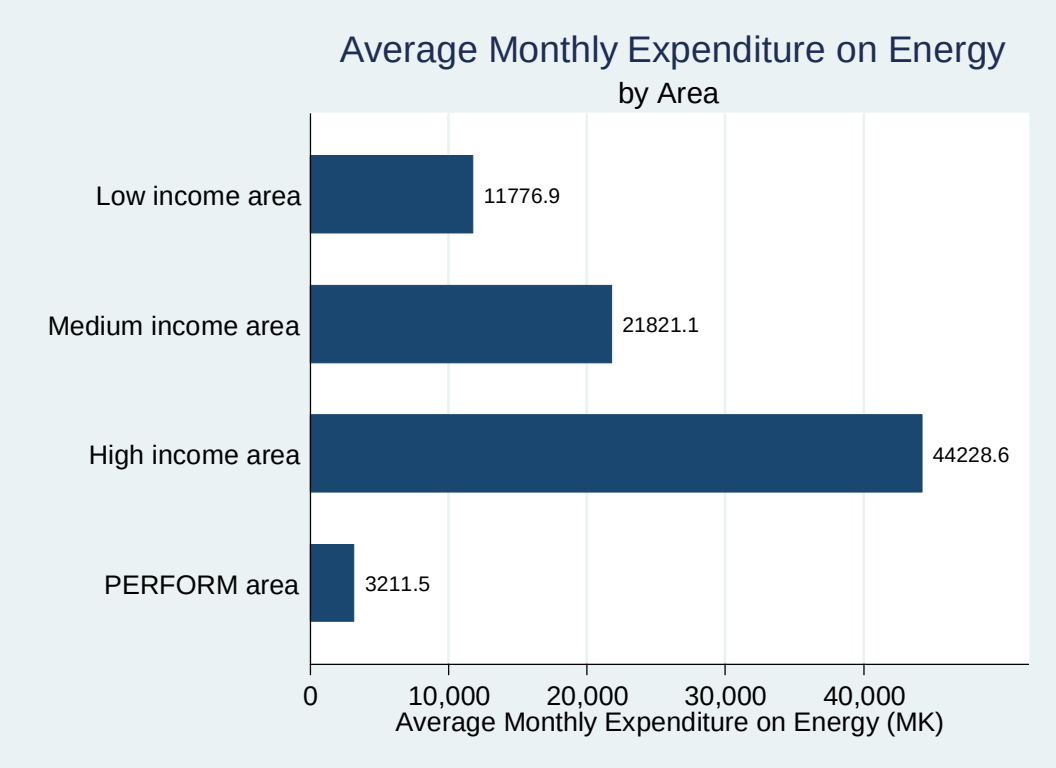

Figure 1: Average monthly expenditure of fuel energy

Furthermore, the proportion of income spent one fuel energy was analyzed. It was found low income areas spend proportionally higher (13%) on fuel energy as compared to middle and high income areas and rural (PERFORM areas) who allocate less than 8% of their expenses to fuel energy.

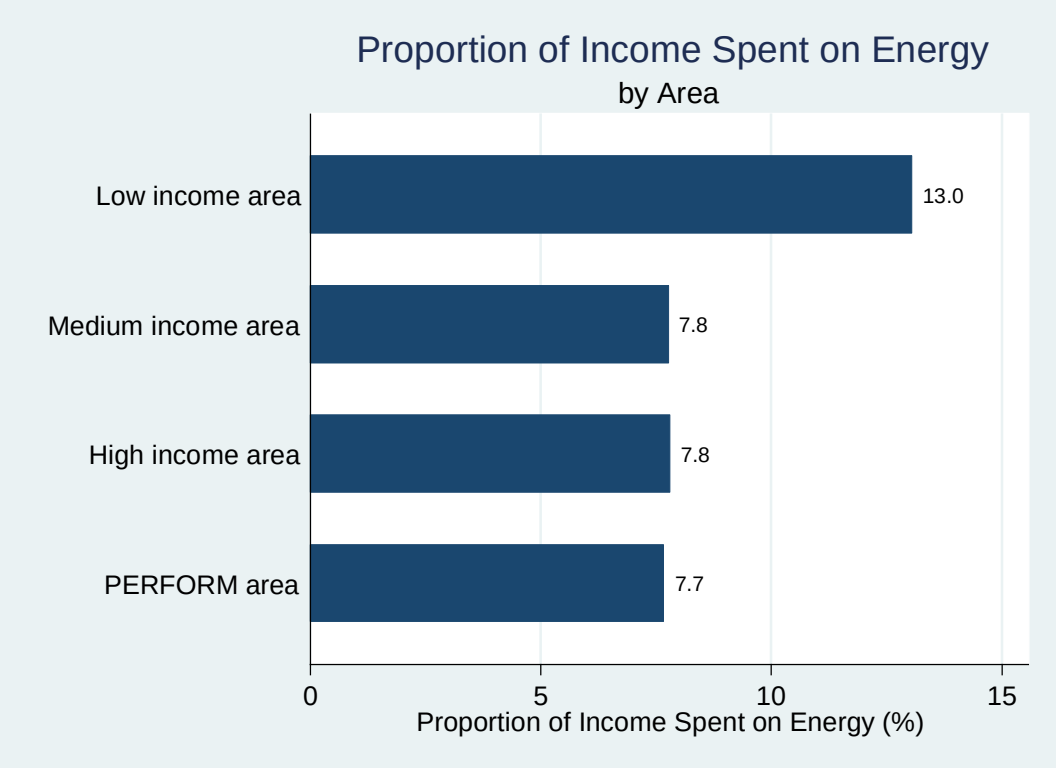

Figure 2: Proportion of income spent on fuel energy

3.1.3. Type and Choice of Cooking Fuels

It is not surprising that the study findings indicate that most households use firewood and charcoal. From **Figure 3** below, 90.6% of households in rural areas (PERFORM impact areas) use firewood with 8.8% using charcoal and virtually no use of electricity and LPG. In the low income areas, 91.2% of the households use charcoal, with 6.6% and 2.2% using firewood and electricity for cooking respectively. In Malawi biomass is the main source of fuel energy for the majority of the population. This is the case because of high poverty levels as well as low coverage of electricity and other alternative sources of energy (Yaron et al., 2010). It is reported that biomass account for 97% total primary energy supply out of which 59% is used in its primary form as firewood (52%) and residues (7%), while the remaining 41% is converted into charcoal.

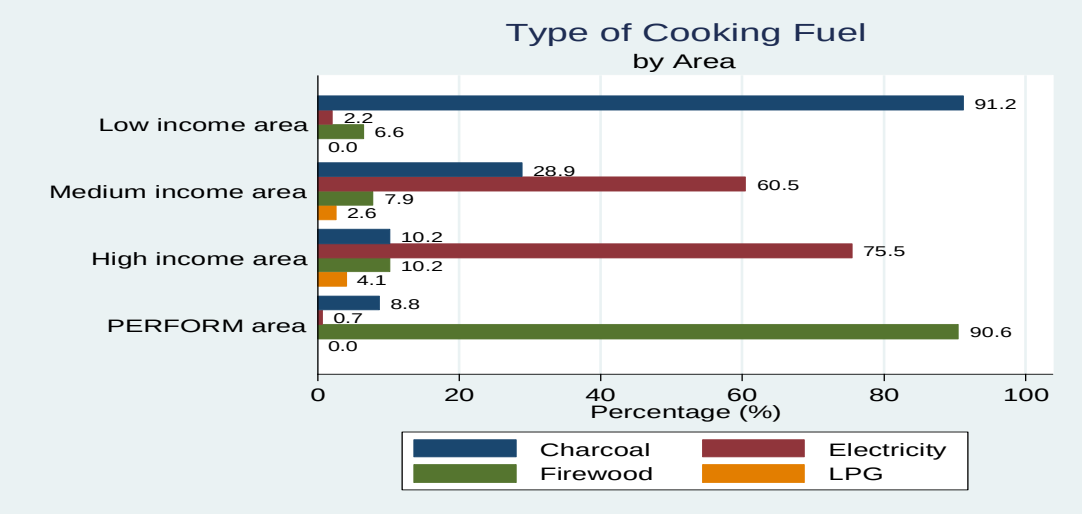

Figure 3: Preferred type of cooking fuel by area

Low income areas showed a similar pattern in use of LPG as rural areas. High income and middle income areas have a common pattern in terms of the composition of cooking fuels used. Electricity is the most widely used fuel at 75.5% in the high income areas and 60.5% in the middle income areas. This is followed by use of charcoal at 10.2% and 28.9% respectively. LPG is used in these areas, albeit by a small proportion of households. Only 4.1% of households in high income areas use LPG and 2.1% in middle income areas, overall only 2% of the urban population and 0.35% of the overall sample population use LPG – this is in correlation with a baseline study by the Sustainable Energy for All (SE4ALL) which shows only 0.2% of the population in Malawi use LPG. It can therefore be concluded, in general terms, that firewood is the cooking fuel for the rural areas, charcoal for the low income areas and electricity for the middle and high income areas. The study team conducted further investigation of the reasons for a household's choice of cooking fuel as presented in **Figure 4** below.

Income plays an important role in the explanation of inter-fuel substitution in a household. However, according to empirical evidence from a considerable number of households interviewed, household fuel choices are influenced by many other factors. It is also worth mentioning that a household may 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. During the study only 5 LPG households were monitored, of the 5 households 3 indicated they prefer LPG because it is cheaper as compared to other fuels. This may not be a representative data, the researcher will get more detail on this during the second milestone where the consumer questionnaires will be administered purposively targeting LPG users in both institutions and households across Malawi.

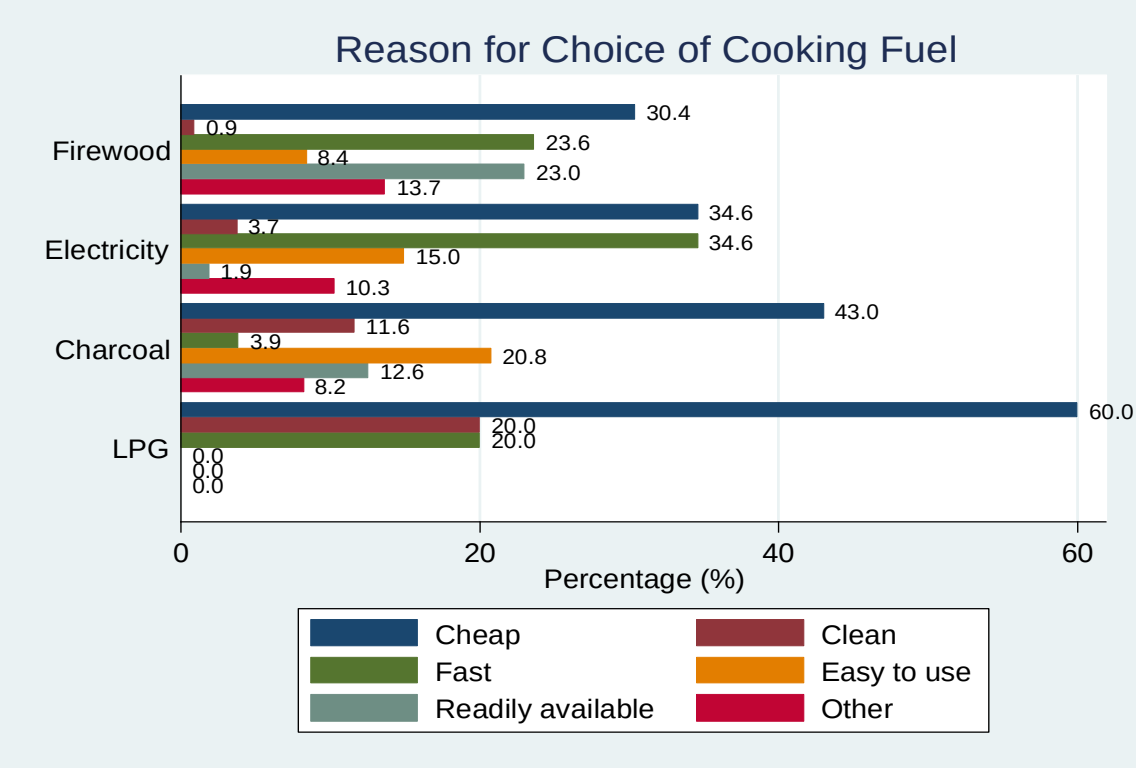

Figure 4: Reason for preference of cooking fuel

3.1.4. Type of Cooking Appliance

The study found that the most common type of cooking appliance followed the pattern of the fuel of choice in that particular area. Rural areas were more likely to use an open fire (68%), low income areas reported mostly using a charcoal stove (88%) while middle income (55%) and high income (72%) areas reported using an electric cooker. The figure 5 below illustrates choice of cooking appliance by location.

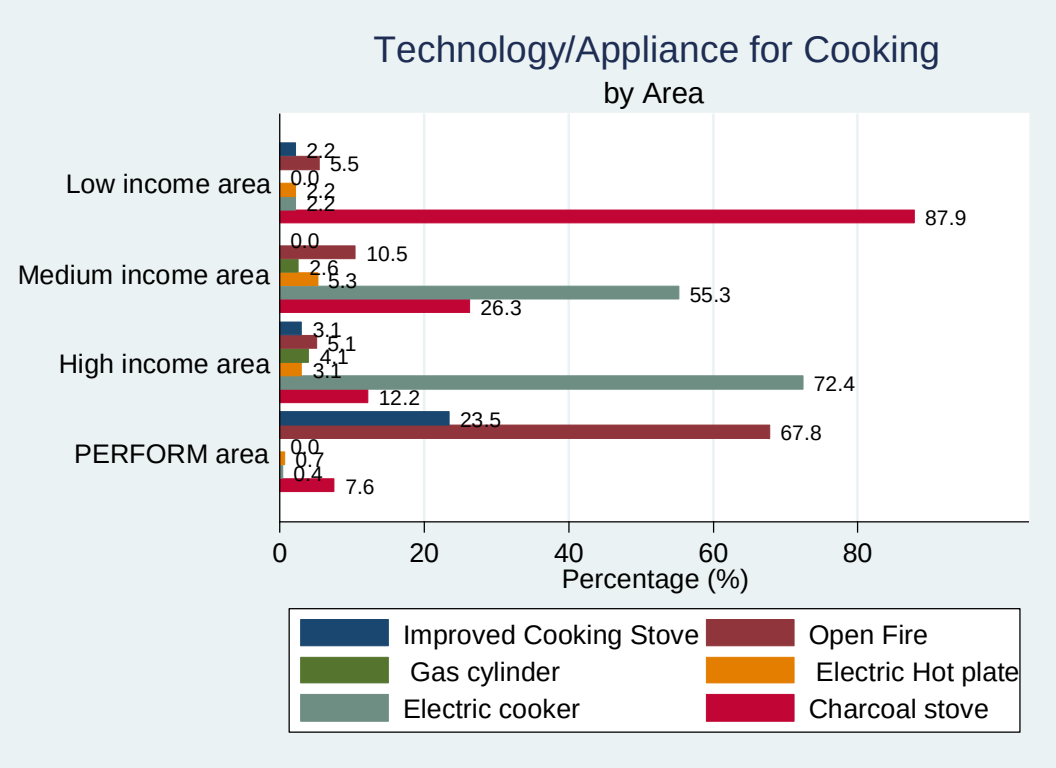

Figure 5: Type of preferred cooking appliance

3.1.5. Gender of Cook

We also examined the question of which sex of the household members does most of the cooking in the household. Results are presented in **Figure 6** below. The results show that cooking in all the four areas is predominantly a feminine activity. This is not surprising as traditionally in Malawi most household chores are handled by women. This has an implication in understanding the population group that is at the highest risk of exposure to unhealthy fumes from cooking fuels. In rural areas, the fuel of choice is firewood which is known to emit larger amounts of fumes hence exposing women to considerable health hazards.

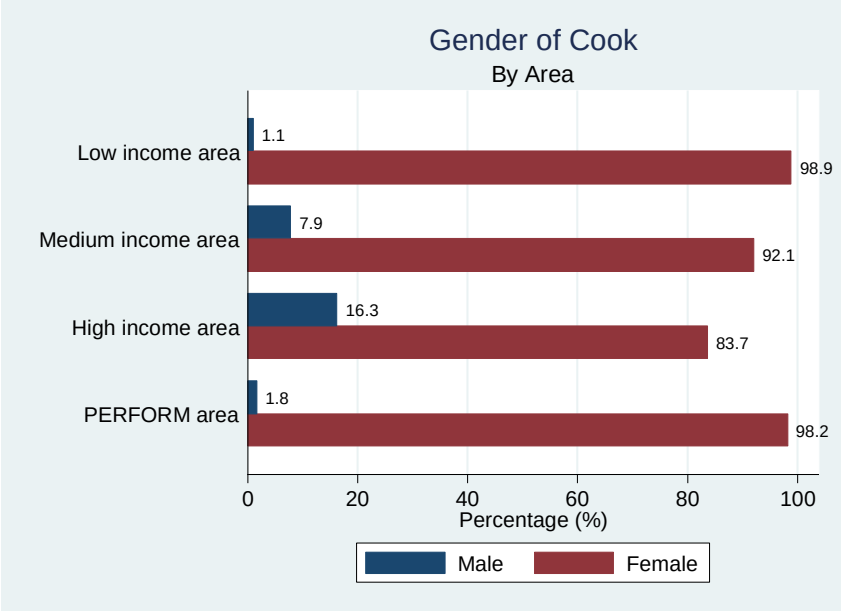

Figure 6: Gender of person cooking meals

3.1.6. Average Cooking Time and cost of the fuels

The study team collected data on time and cost taken to cook a standard meal (Nsima; Potatoes; Meat; Vegetables) in Malawian households. It was found that LPG is the most time efficient cooking fuel with an average of 20.5 minutes to cook a standard meal. The least time efficient fuel was found to be firewood with an average time of 31.63 minutes as presented in **Figure 7** below.

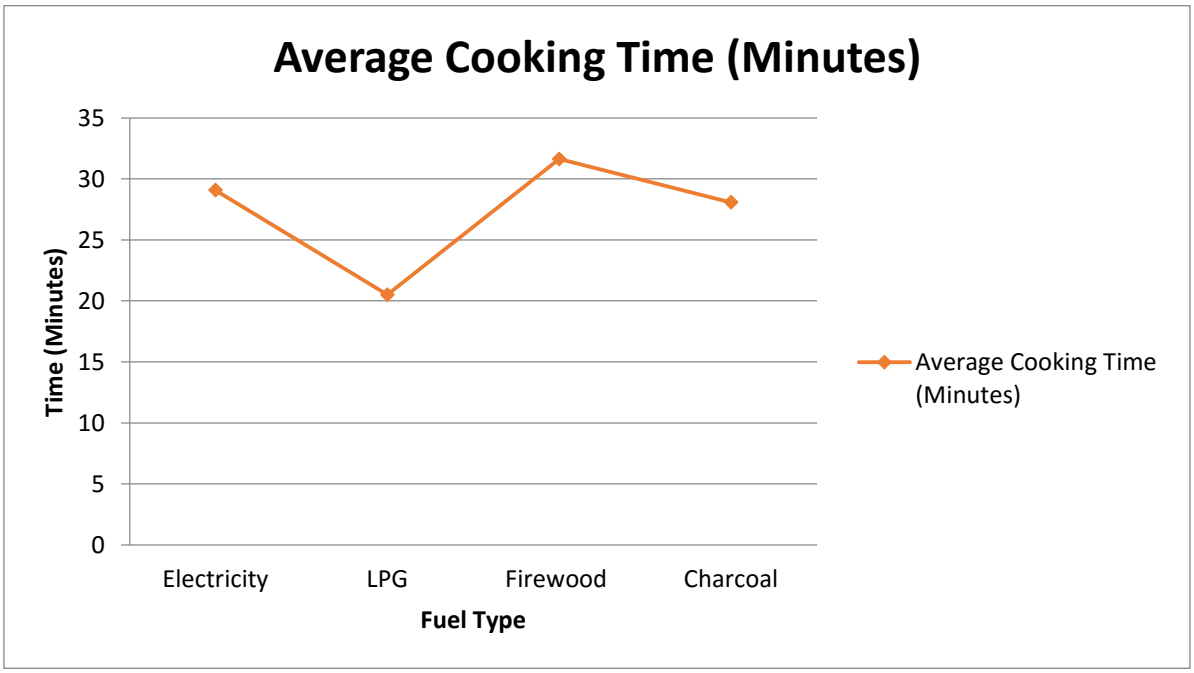

Figure 7: Average meal cooking time (minutes)

The time analysis results are similar to findings elsewhere such as Anozie et.al. (2006) who found that in Nigeria, fueld wood was the least time efficient fuel. This pattern in confirmed when water boiling test was conducted as presented in the **Section 3.2** below. The team further conducted a cost analysis to determine the most cost effective fuel type. The **Figure 8** below shows that electricity was reported to be the most expensive fuel and firewood was the cheapest. LPG was rated second in terms of cost among sampled households. However, this might be a result of limited sample of households that have experience using gas for cooking. The study on supply and demand of LPG in Malawi will conduct further comparative cost analysis of these fuels and confirm the findings.

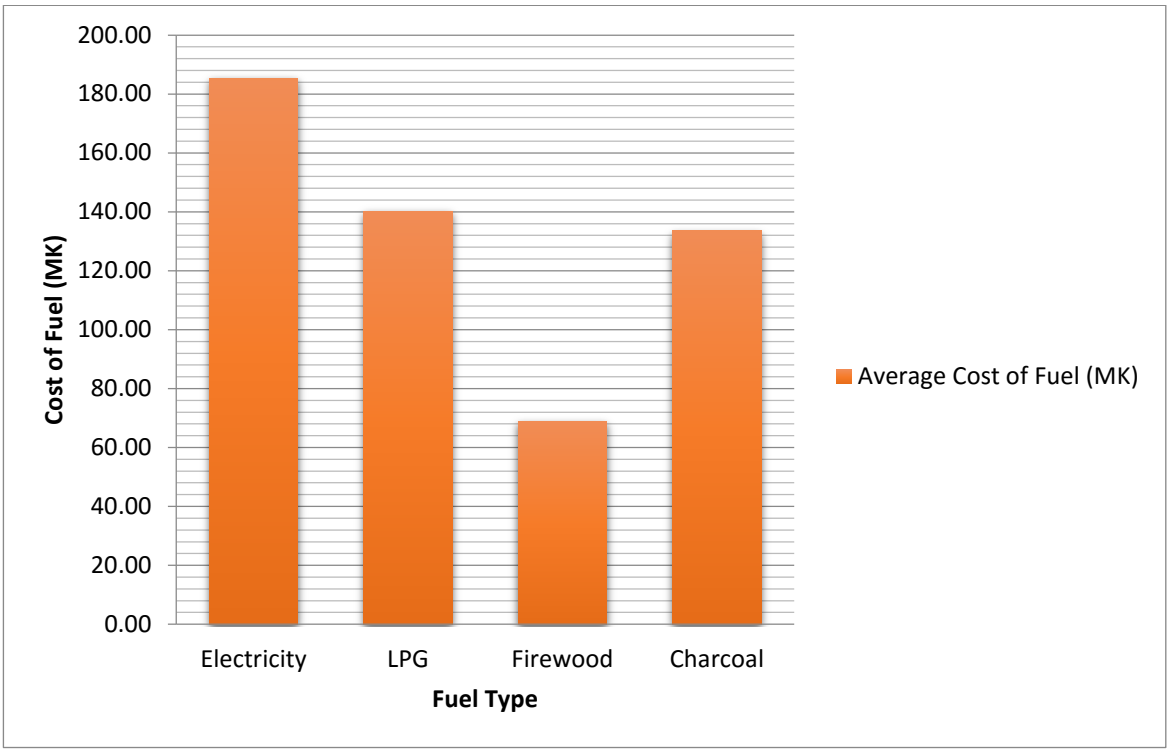

Figure 8: Average cost of fuel per meal

Performance of a fuel was measured in terms of time taken for a particular food item to be cooked using that fuel and the monetary cost of the fuel used in the process. To ensure comparability, performance was assessed for specific food items. Top 10 foodstuffs mostly cooked: Nsima, Rice, Potatoes, Tea, Porridge, Meat, Fish, Eggs, Vegetables and Beans were considered. However, in the analysis that follows Fish, Eggs and beans have been excluded because one or more cooking fuels was not used to cook these food items during the period of observation. This was particularly true for LPG. The results of individual time-cost analysis for cooking common meals in Malawi are presented in the figures that follow below:

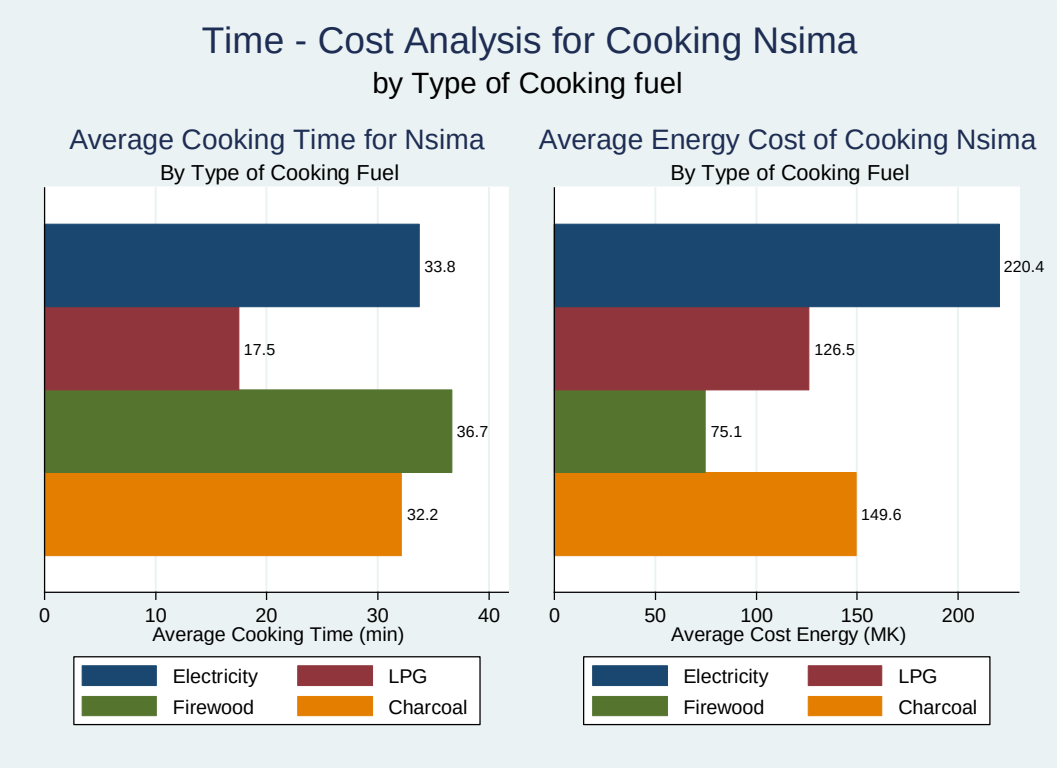

Figure 9: Time-cost analysis for Cooking Nsima by Type of Cooking Fuel

The same pattern of performance of the cooking fuel is repeated when we use, in turn, Rice, Potatoes and Porridge as the food item, as shown in **Figures 11 – 12 b**elow. LPG is consistently the most efficient fuel in terms of time, while firewood is the least cost fuel.

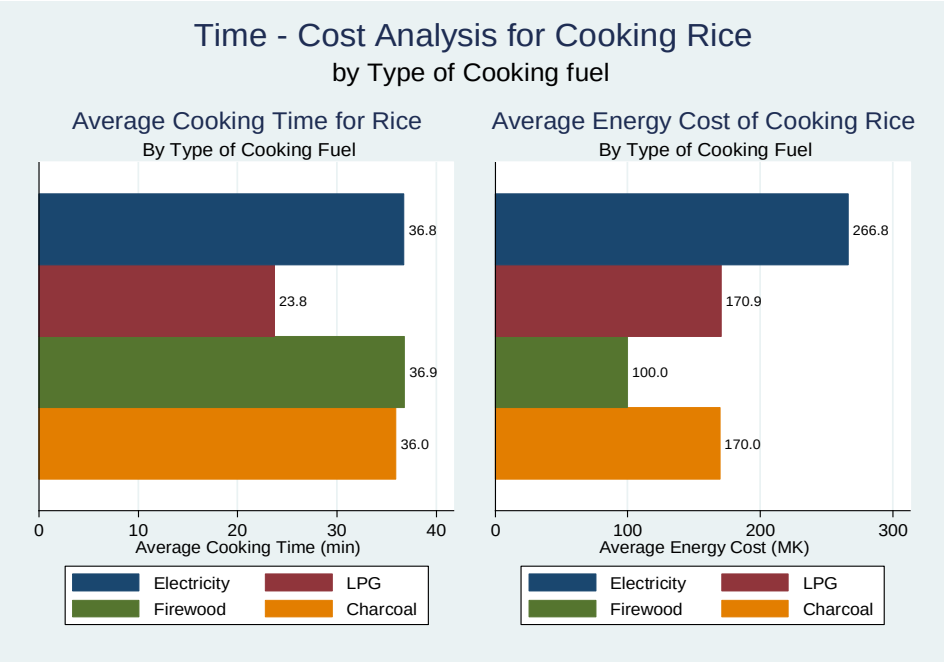

Figure 10: Time-cost Analysis for Cooking Rice

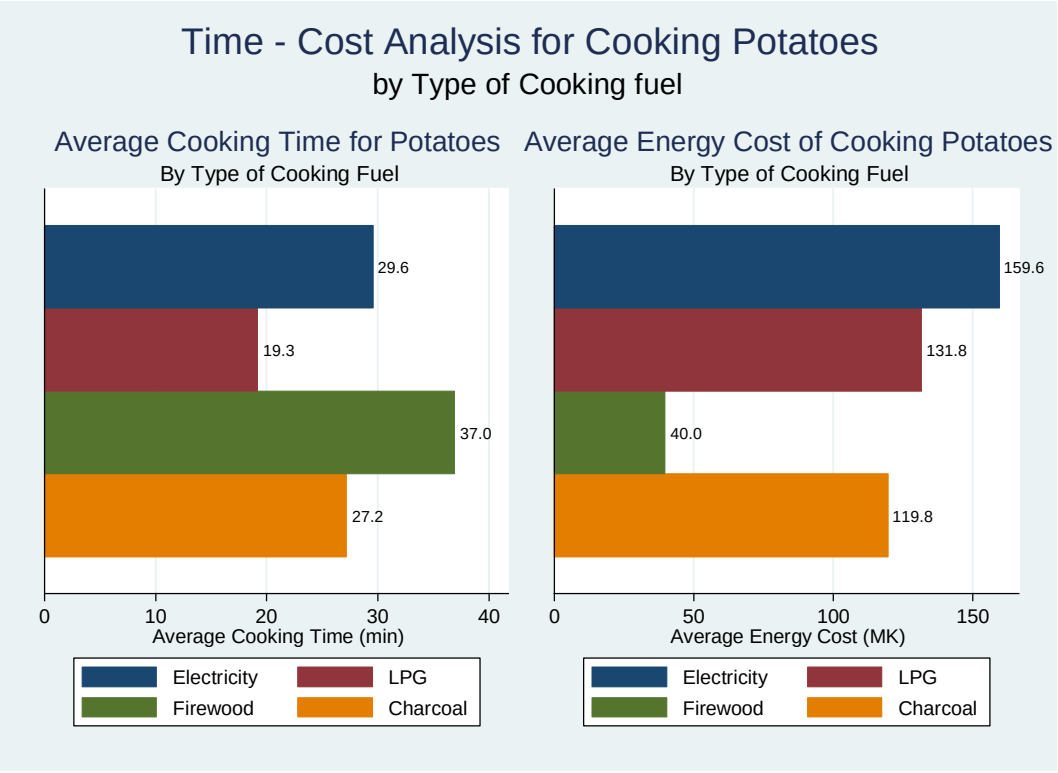

Figure 11: Time-cost Analysis for Cooking Potatoes

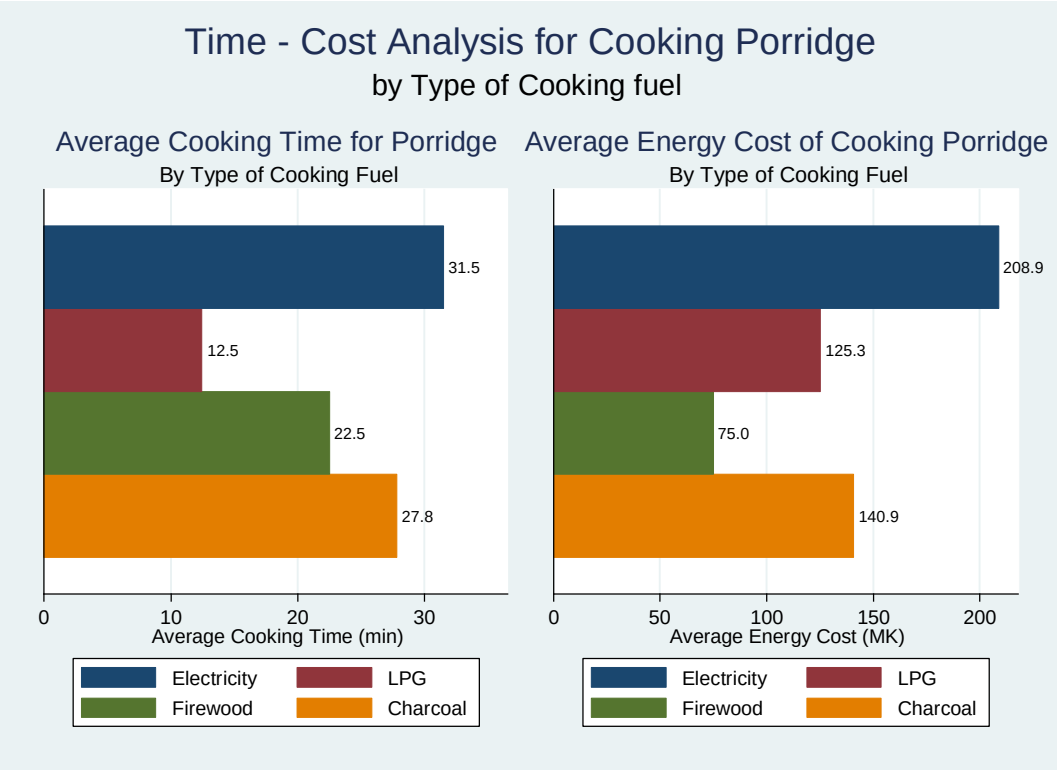

Figure 12: Time-cost Analysis for Cooking Porridge

3.2. Fuel Efficiency Tests

3.2.1. Water Boiling Tests

The time to boil water was measured from the time the fuel was ignited to the time when the water started boiling at local atmospheric pressure. The Gas stove was the fastest to bring water to boiling point, followed by Chitetezo Cook stove. Electricity was the slowest taking about 28 minutes to heat water to boiling point at local atmospheric pressure. It was also observed that the improved Environ fit stove was faster in boiling water compared to the ceramic Jiko Cook stove. It took approximately half the time to boil water on the Environ fit Cook stove. It should be noted that the electric hot plate used in this study had an inbuilt thermostat that controlled power even during heating up therefore the outcomes on electricity test should take into account the type of the appliance used during the tests. **Figure 13** below refers.

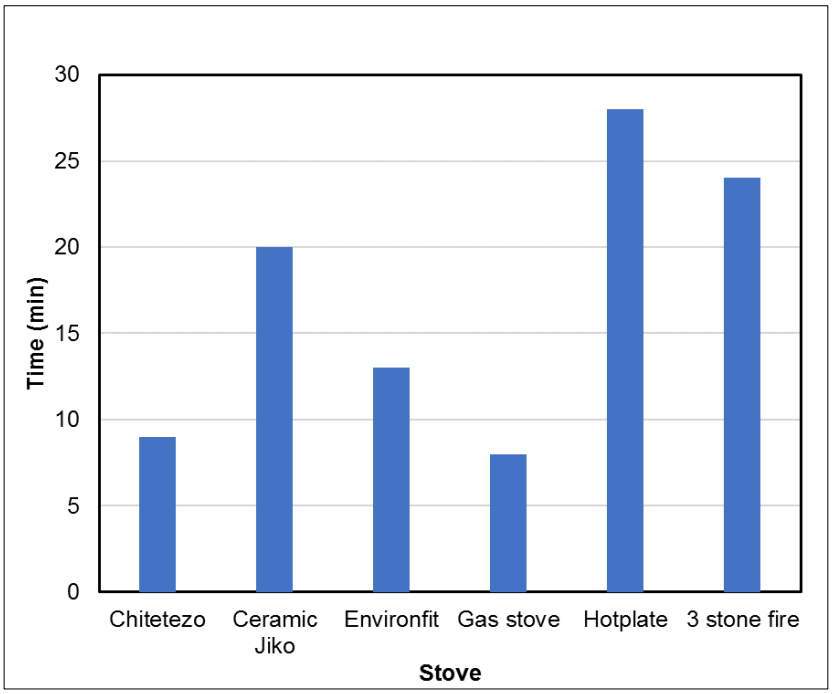

Figure 13: Time taken to boil water

Table 3: Time taken to boil water by stove type

Type of cook stoves	Time (min)	Rank (fastest to slowest)
Gas Stove	8	1
Chitetezo Stove	9	2
EnvironFit Stove	13	3
Ceramic Jiko	20	4
3 Stone	24	5
Hotplate	28	6

3.2.2. Fuel Consumption Tests

Temperature compensated specific fuel consumption at 75^{o}C was used to assess amount of fuel required from cold start to boil the water. The temperature compensated specific fuel consumption eliminates the effect of varying start temperature and boiling point in the determination of fuel consumption. Firewood had the highest consumption rate followed by local charcoal. At third position was Kawandama Charcoal and the lowest consumption rate was attained when using LPG. Fuel consumption tests on different types of cooking stoves used showed that the 3 stone cook stove had the highest consumption rate (four times higher than the Chitetezo cookstove). The Chitetezo cook stove was second followed by the Environ fit stove and Ceramic Jiko stove in third and fourth position respectively. The tests furthermore revealed that the gas stove had the least fuel consumption rate as presented in **Figure 14** below.

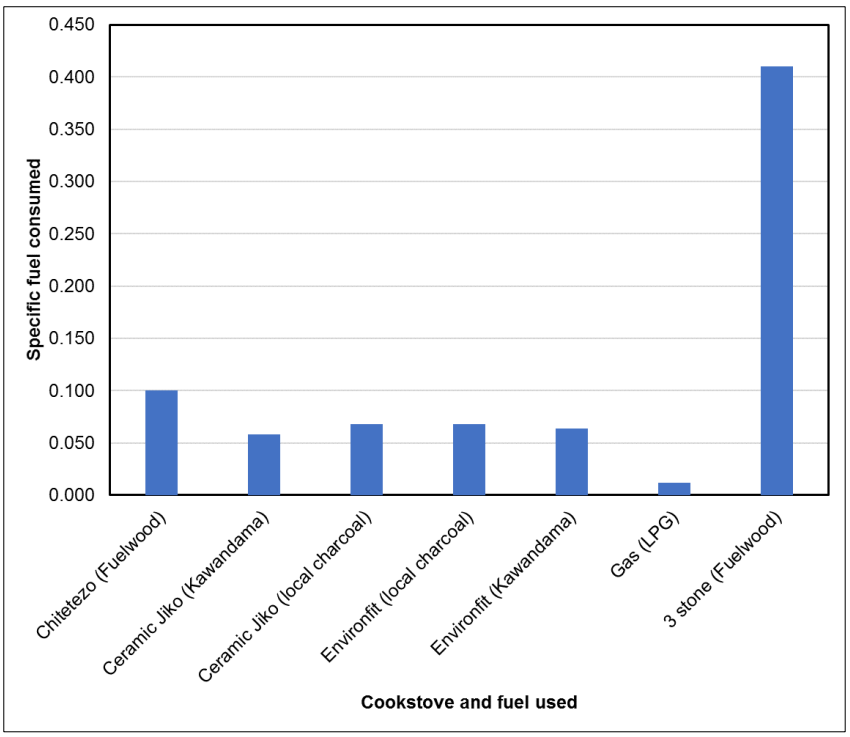

Figure 14: Fuel consumption test

Table 4: Fuel consumed during water boiling test

Cookstove (Fuel)	Specific fuel consumed
Chitetezo (Firewood-B)	0.100
Ceramic Jiko (Kawandama)	0.058
Ceramic Jiko (local charcoal)	0.068
Environfit (local charcoal)	0.068
Environfit (Kawandama)	0.064
Gas (LPG)	0.012
3 stone (Firewood-A)	0.410

3.2.3. Fire power of the stove

The average power output of the stove was assessed by determining the ratio of the fuel energy consumed per unit time expressed as fire power. The 3-Stone Fire had the highest fire power seconded by the Chitetezo Cook stove. The Environ fit Stove was third followed by the Ceramic Jiko Stove. The LPG stove gave the lowest fire power values comparatively as presented in **Figure 15** below.

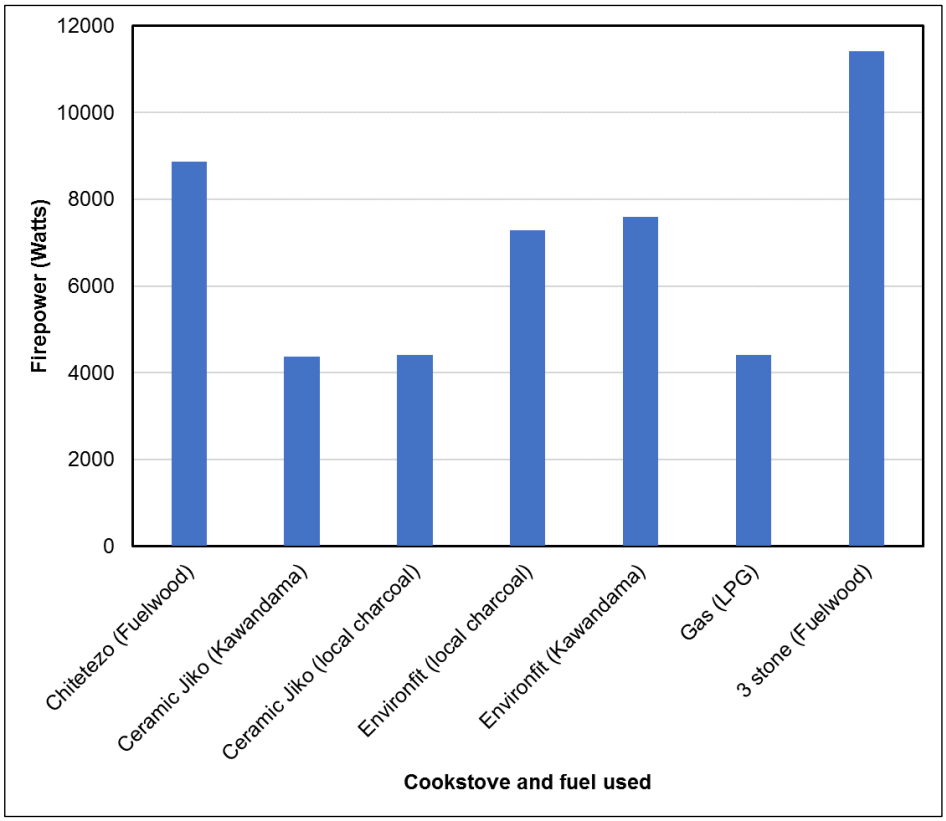

Figure 15: Cook stove fire power

Table 5: Fire Power of Cook Stoves

Fuel and stove	FPH (Watts)
Chitetezo (Firewood B)	8873
Ceramic Jiko (Kawandama)	4373
Ceramic Jiko (local charcoal)	4412
Environfit (local charcoal)	7285
Environfit (Kawandama)	7598
Gas (LPG)	4406
3 stone (Firewood A)	11414

3.2.4. Thermal Efficiency of Fuels

Thermal efficiency represents the ratio of the work done by heating and evaporating water to the energy supplied by burning fuel. When the thermal efficiency was assessed, local charcoal gave the highest thermal efficiency followed by LPG and firewood. Kawandama Charcoal gave the lowest thermal efficiency as presented in **Figure 16** below.

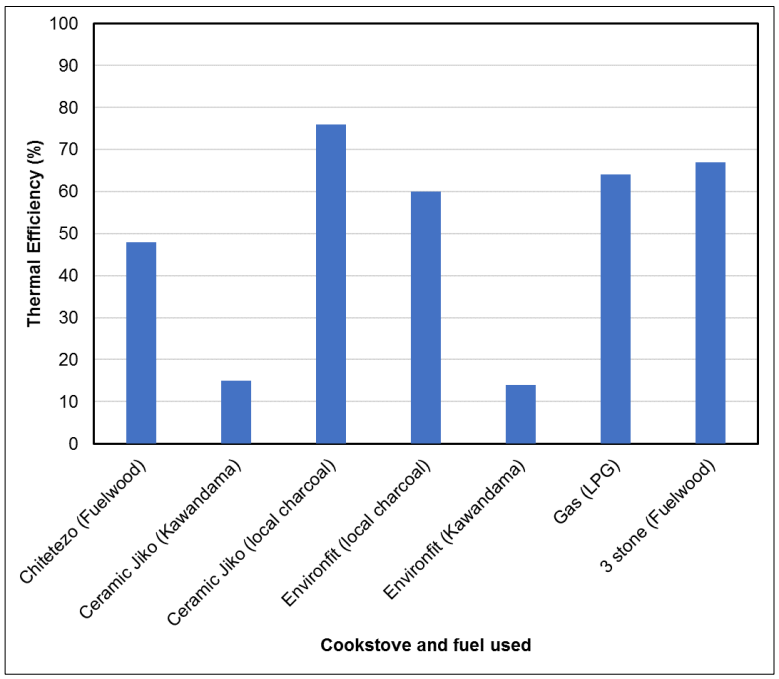

Figure 16: Cook stove thermal efficiency

Table 6: Cook stove thermal efficiency (%)

Fuel	Thermal efficiency (%)
Chitetezo (Firewood B)	48
Ceramic Jiko (Kawandama)	15
Ceramic Jiko (local charcoal)	76
Environfit (local charcoal)	60
Environfit (Kawandama)	14
Gas (LPG)	64
3 stone (Firewood A)	67

3.2.5. Fuel Emission Tests

All the cook stoves had similar emission outputs except LPG which did not emit CO and comparatively emitted less CO_2, NO_2 and SO_2. It was also observed that when the Environ fit Cook stove used Kawandama Charcoal less SO_2 was emitted. The researcher suggests further study should be conducted to determine if the process of production of Kawandama Hills charcoal has an effect on the level of emissions produced at cooking.

Table 7: Fuel emissions test data

Fuel	CO_2 (ppm)	NO_2 (ppm)	SO_2 (ppm)
Chitetezo (Firewood B)	0.4	0.8	22
Ceramic Jiko (Kawandama)	0.4	0.9	86
Ceramic Jiko (Local charcoal)	0.4	0.9	121
Environfit (Local charcoal)	0.4	0.9	86
Environfit (Kawandama)	0.4	0.9	43
Gas (LPG)	0.3	0.7	4
3 stone (Firewood A)	0.4	0.8	14

The values for Carbon monoxide (CO) varied with height/distance from the Cook stove as in **Table 8** below. The higher the distance of the stove from the fire, the higher the level of emissions recorded. It should be noted that firewood gave the highest CO values compared to charcoal while no CO emissions were detected in LPG and Electricity cook stoves.

Table 8: Carbon monoxide emissions test data

Fuel	At 30 cm (ppm)	At 60 cm (ppm)	At 1 m (ppm)	At 2 m (ppm)
Chitetezo (Firewood)	690	133	19	19
3 stone (Firewood)	160	113	56	24
Ceramic Jiko (Kawandama charcoal)	540	360	310	116
Ceramic Jiko (Local charcoal)	585	210	177	60
Environfit (Local charcoal)	630	260	210	103
Environfit (Kawandama charcoal)	61	72	73	82
Gas (LPG)	0	0	0	0
Hot plate (Electricity)	0	0	0	0

4. CONCLUSION

The study has investigated the cost and efficiency of four cooking fuels (electricity, LPG, firewood and charcoal) using household surveys and laboratory experiments. Household surveys were conducted in rural (PERFORM impact areas) and urban areas. A sample of 1,500 households (1200 rural; 300 urban) were interviewed during household surveys and five laboratory tests (water boiling; fuel consumption; fire power; thermal efficiency and; emissions test) were conducted.

Household surveys focussed on poor rural based families and urban residents disaggregated based on income level of their location (low, middle and high income urban areas). The researchers therefore analysed the results to reflect this variation before drawing conclusions on the results presented in this report. Household surveys found that Firewood is the main cooking fuel in rural areas of Malawi as confirmed by household surveys conducted in communities surrounding Perekezi forest in Mzimba, Ntchisi forest in Ntchisi district and Liwonde in Machinga district. The pattern of fuel choice was different in urban areas. Low income urban areas across all four main cities of Malawi prefer using charcoal while middle and high income areas are more likely to use electricity for cooking. The study has confirmed low uptake of LPG as a cooking fuel with only 2% of the urban population monitored using the fuel and 0.35% of the total population studied use the fuel for cooking. It has been found that cost consideration accessibility of the fuel influences choice among households. The gender of household head was found not to have an impact on the choice of fuel type. However, other factors such as income; size of household; type of food to be cooked and education level had an influence on the choice of fuel used. It was found that choice of cooking appliance used followed the pattern of energy of preference; rural households using firewood were more likely to report using a 3 stone fire while urban households using electricity preferred an electric stove.

Time and cost analysis of the four cooking fuels at household level revealed that LPG was the most efficient followed by Charcoal. Electricity and Firewood had marginal differences. The cost of cooking fuels was assessed based on what it costs the households to cook a particular food material using a particular cooking fuel type. The study has shown that Firewood is the cheapest source of cooking fuel and Electricity the most expensive. There were ties and inconsistencies on the costs between LPG and Charcoal. Regarding household expenditure on fuels, it was found that urban households spend on average MK25, 943 on cooking fuels compared to MK3, 211 for rural households. The researchers established that rural households usually source firewood from their fields and forest reserves hence the low level of expenditure of fuels. Furthermore, household surveys established that low income urban areas allocate more resources (13% of income) towards purchase of fuels as compared to other locations (rural and middle – high income urban areas) who allocate on average 8% of their income to household fuel energy expenses.

Out of five fuel efficiency tests (water boiling; fuel consumption, fire power, thermal efficiency and emissions level) conducted in at laboratory setting for the four cooking fuels, LPG gas was found to be the most efficient fuel in terms of time, fuel consumption and level of emissions. A comparison test of cooking stoves showed that the Enviro fit Cook stove was more efficient than Ceramic Jiko. However, the amount of charcoal consumed was comparatively similar. The Chitetzo Mbaula (Firewood B) was more efficient than 3 stone-fire (Firewood A) when used with firewood. Firewood and Charcoal produced more CO than any other type of fuels, making them unsuitable choices as they exposed women to hazardous fumes.

This quantitative study has found that LPG is a competitively cost efficient cooking fuel in comparison to other common fuels available in Malawi. LPG ranked first in the water boiling test and took less time to cook a standard meal at household level. In terms of time cost efficiency, LPG competed well with other fuels and was rated second in the thermal efficiency test in the laboratory environment with negligible emission of hazardous gases.

5. RECOMMENDATIONS

The following recommendations are made based on the household survey and laboratory experiments conducted on the four cooking fuels:

i. Firewood is preferred and cheap source of cooking fuel in rural areas, therefore efforts should be made by government, private sector and other development partners to promote efficient cooking methods.

ii. Charcoal was found to be the preferred cooking fuel for low income urban areas. It is recommended that efforts to address charcoal use, such as promoting efficient stoves and other alternative fuels should primarily target this population group.

iii. The study revealed low uptake of LPG as a cooking fuel across Malawi despite household survey data on time and cost efficiency showing that the fuel is the most efficient. There is therefore need to increase access to knowledge on the advantages of LPG and implement strategic initiatives such as subsidies and credit facilities for acquisition of gas cylinders, especially for urban based households.

iv. The study has confirmed that women do most of the cooking in both urban and rural areas of Malawi. Due to high risk of exposure to fumes, it is recommended that adoption of stoves that have been found to emit fewer fumes such as the Environfit, should be promoted. Furthermore, educational messages should be produced and disseminated to people living in areas regarding the health hazards of exposure to fumes.

v. Fuel efficiency laboratory tests established that LPG is the most efficient fuel in terms of time, fuel consumption and cleanliness. It is therefore recommended that these benefits should be effectively communicated to the general population, primarily targeting urban communities. Behavioural change activities would be recommended to change perceptions, attitudes and practices of Malawian households in relation to LPG use.

vi. The Environ-fit cook stove was found to be the most efficient when using charcoal as a cooking fuel. The stove should therefore be given more attention and promoted among low income urban populations who are more likely to use charcoal for cooking.

vii. The Chitetedzo stove was found to be more efficient when using firewood as a cooking fuel. The stove should therefore be given more attention and promoted among rural communities who are more likely to use firewood for cooking.

viii. Demand and supply study is recommended to understand the impact of supply chains on the cost and uptake of different cooking fuels, especially identification of barriers to adoption of LPG.

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7. APPENDIX

7.1. Household Questionnaire

Hello, my name is _____I am working with PERFORM activity under Practical Action. Your household has been randomly chosen to participate in this study. We are trying to learn more about how families using different fuels for cooking. The survey is a confidential exercise and your name will not be disclosed anywhere. Please feel free to answer these questions as they will help in future community development. Would you be willing to have a discussion with me?

Moni, dzina langa ndine_____ ndipo ndimagwira ntchito ndi polagalamu ya PERFORM ku bungwe la Practical Action. Bungwe limeneli lili pakafukuku wofuna kudziwa momwe anthu akugwiritsa njira zosiyana siyana zophikira. Nyumba yanu ndi imodzi mwa nyumba zomwe zasankhidwa mudela lino kuti mutenge nawo mbali pakafukufukuyu. Ine ndikukutsimikizilani kuti ndidzasunga chininsi pazokambilana zathu makamaka zokhudza banja. Ndipo mukhale omasuka pazokambilana zathu chifukwa zomwe tikambilane pano zithandiza pokonza mapulani a zachitukuko chokhudza dela lino. Sindidziwa ngati muli omasuka kuti **tipilile kukambilana?**

*If **NO**, mark here ☐ and end interview.*

*If **YES**, mark here ☐ to acknowledge that consent for respondent was give*

SECTION B: DEMOGRAPHY

a) Sex of respondent (1=M; 2=F)____

b) Age of respondent: _____

c) Sex of household head (1=M; 2=F)____

d) Number of Adult Men ( ) and Women ( )

e) Number of Children under five years living in the house ( )

f) Number of Children over five years living in the house ( )

g) Age and Education of Adults:

	Age	Education Level		Age	Education Level
Adult 1	( )	( )	Child 1	( )	( )
Adult 2	( )	( )	Child 2	( )	( )
Adult 3	( )	( )	Child 3	( )	( )
Adult 4	( )	( )	Child 4	( )	( )
Adult 5	( )	( )	Child 5	( )	( )
Adult 6	( )	( )	Child 6	( )	( )
Adult 7	( )	( )	Child 7	( )	( )

1=Primary; 2=Secondary; 3=Tertiary; 99=No education

SECTION C: HOUSEHOLD INCOME & EXPENDITURE

a). Is there one or more adults, over 18 years, in the household that is earning a regular income to meet the needs of the household?

Yes = 1 No = 2

A regular income means an income that is expected at certain intervals that can be relied on e.g. daily, weekly, monthly or seasonally.

b). If yes: What is the main source of that income?

1 = Sale of farm produce (farming)

2 = Labour (self-employed/non-farm wage labour)

3 = Wage employment (formal employment)

4 = Remittance (transfers from children/relations)

5= Small businesses

5 = Other (specify) _____

c). Tell me how much was your Total Monthly Income from all of your sources (in Malawi

Kwacha)_____

d). How much money does your household spend on the following items?

CODE	EXPENSE CATEGORY	MONTHLY EXPENDITURE (MK)
C1	House rental	
C2	Food purchases	
C3	Energy bills (electricity; paraffin; firewood; charcoal)	
C4	Water bills	
C5	School fees	
C6	Labourers	
C7	Other (specify)	

SECTION D. ENERGY ACCESS AND USE AT HOUSEHOLD LEVEL.

a). Do you have access to or use the following? (circle as many choices)

i. Grid electricity (Yes / No)

ii. 3-Stone Fire (Yes / No)

iii. Candles (Yes / No)

iv. Paraffin (Yes / No)

v. Battery torch

vi. Solar torch

vii. Improved cook stove (Yes/No)

viii. Other (Specify)

b). Which type of fuel does your household usually use? (select one)

1=Electricity; 2=LPG; 3 =Firewood;4=Charcoal;5=Paraffin)

c). Give two reasons why you prefer the selected fuel type from above?

_____

_____

d). Roughly how much money do you spend in a month on the following cooking fuels

□ Charcoal (MWK) □ Firewood (MWK) □ LPG (MWK)

□ Paraffin (MWK) □ Electricity (MWK)

e). How many times, on average do you cook in your home?

1- Up to 3 Times; 2- 4-5 Times; 3 - Above 5 Times

f). What cooking devices /appliances do you use? Please tick the one applicable

1 = Improved Cooking Stove; 2 = Open Fire (Three stone Fire); 3= Gas Cylinder; 4=Electric Hot Plate;

5=Electric Cooker; 6=Charcoal stove

g). *Who does the most of the cooking in the house? (M=1; Female=2)*

h). Is the one who does most of the cooking employed or a member of the family/relations? (1=employed; 2=member of family or relation

i). Source of charcoal: 1= Government Forest; 2= Private/Commercial Seller; 3= Farm; 4= Woodlots; 5= Purchase from market

j). Source of firewood 1= Government Forest; 2= Private/Commercial Seller; 3= Farm; 4= Woodlots; 5= Purchase from market

SECTION E. DAILY ENERGY CONSUMPTION DATA AT HOUSEHOLD LEVEL

Name of Respondent:_____ Contact Number: _____ Sex:_____

Locations:_____ Name of Interviewer:_____ Dates:_____

Day	**Type of Cooking Fuel** (1=Electricity; 2=LPG; 3 =Firewood;4=Charcoal;5 =Paraffin)	**State what item was cooked or heated (food, water) using the fuel**	**Time taken (minutes) for each item.**	**Quantity/Units of fuel used for each item.**	**Unit Cost of the Fuel Used.**	**Total Cost of Fuel Used**	**Frequency of cooking or heating the listed items per day**

7.2. Fuel Efficiency Test Procedure

The efficiency of the fuels and performance of the cook stoves were assessed using Water Boiling Test (a digital thermocouple thermometer; a digital weighing scale; an oven; a stopwatch; a power quality analyzer; Gas detectors; an aluminium pot, sand bath, tongs for handling charcoal, and gloves.

7.2.1. Key Activities Conducted

a). Moisture content determination

Usually the moisture content of wood, when well-dried, contains 10-20% water, while fresh cut wood may contain more than 50% water by mass (wet basis). Although households use fuels with varying moisture content, cook stove testers measured the moisture content and account for it in their stove performance calculations. A weighing scale with an accuracy of ±1 g was used to weigh a sample of about 200 – 300 g of the solid fuels (charcoal or firewood) randomly selected from the fuel stock. The moisture content of the solid fuels were determined by weighing a sample of the air-dry fuel (Mass of fuel) wet and weighing it again after it has been completely dried in an oven, (Mass of fuel) dry. To dry the sample, the specimen was put in an oven set between 100 ^{o}C and 110 ^{o}C. The oven temperature was carefully controlled so that it did not exceed 110°C. The sample was removed from the oven and weighed every two hours until the mass no longer decreased. The moisture content of the fuels on wet basis (MCwet %) was calculated using the following expression (**WBT Version 3.0**) :

$$\mathrm{MC}_{\mathrm{wet}}(\%) = \frac{\text{Mass of } fuel_{\mathrm{wet}} - \text{Mass of } fuel_{\mathrm{dry}}}{\text{Mass of } fuel_{\mathrm{wet}}} \times 100$$

b). Local boiling point determination

The reference local boiling point was determined by boiling distilled water in the pot to a constant rolling boil. It should be noted that the local boiling point is affected by several factors which included altitude, minor inaccuracies in temperature measurement, and weather conditions.

c). Fuel efficiency determination

The following procedure was used in the determination of fuel efficiency:

i. Weighed pots and recorded the mass;
ii. Measured and filled in the pot 3 litres of distilled water;
iii. Using the thermometer, measured the initial temperature of the water;
iv. Determined and recorded the initial mass of fuel that was used for the assessment;
v. Set fuel under test and recorded the time;
vi. Brought the water to boil and recorded time taken;
vii. Determined final mass of distilled water after test
viii. Determined final mass of fuel left after test.

For the Charcoal and fuel wood, the sand bath was used to extinguish the fire before weighing the mass of fuel left after test. In the case of firewood, the mass of the charcoal after test was also recorded.

c). Data Analysis

Data analysis involved calculation of the following performance parameters: fuel consumed, equivalent fuel consumed, specific fuel consumed, fire power and thermal efficiency. Below is a description of the performance parameter with their respective expressions (**WBT Version 3.0**)

i. Fuel consumed

Fuel consumed (f_{cm}) is the mass of wood that was used to bring the water to a boil found by taking the difference of the pre-weighed fuel (f_{hi}) and the fuel remaining at the end of the test phase (f_{hf}) i.e.

$$f_{cm} = f_{hi} - f_{hf}$$

ii. Equivalent fuel consumed

Equivalent fuel consumed (f_{cd}): This is a calculation that adjusts the amount of wood that was burned in order to account for two factors: (1) the energy that was needed to remove the moisture in the solid fuel and (2) the amount of char remaining unburned (Δch). The calculation is done in the following way:

$$f_{cd} = f_{cm} \times [1 - (1.12 \times MC_{wet})] - 1.5 \times \Delta ch$$

Assuming that it takes roughly 2260 kJ to evaporate a kilogram of water, which is roughly 12% of the calorific value of dry wood. As reported by Booker et al. [4], for Charcoal the coefficient 1.12 was replaced by 1.08.

iii. Specific fuel consumed

Specific fuel consumption: Specific consumption can be defined for any number of cooking tasks and should be considered "the firewood required to produce a unit output" whether the output is boiled water, cooked beans, or loaves of bread. In the case of the cold-start high-power WBT, it is a measure of the amount of wood required to produce one litre (or kilogram) of boiling water starting with cold stove. Specific fuel consumption (SC_h) in grams fuel/grams water is given by

$$SC_h = \frac{f_{cd}}{w_{hr}}$$

Where w_{hr} is water remaining at end of tests

iv. Firepower

Firepower FP_c is a ratio of the wood energy consumed by the stove per unit time. It tells the average power output of the stove (in Watts) during the high-power test. Fire power is given by the expression:

$$FP_c = \frac{f_{cd} \times LHV}{60 \times t}$$

Where t is the time in minutes and LHV is the Net calorific value of the fuel (MJ/kg)

Lower heating value (LHV), also called net heating value, is the theoretical maximum amount of energy that can be extracted from the combustion of the moisture-free fuel if it is completely combusted and the combustion products are cooled to room temperature but the water produced by the reaction of the fuel bound hydrogen remains in the gas phase. The LHV values for the various fuels are listed below:

Firewood: 17.6 MJ/kg

LPG: 47.1 MJ/kg

Charcoal 27.6 – 31.5 at 5% MC_{wet}

v. Thermal efficiency

Thermal efficiency (h_c) is a ratio of the work done by heating and evaporating water to the energy consumed by burning fuel.

$$h_c = \frac{4.186 \times w_{hr} \times \Delta T \times 2260 \times w_{cv}}{f_{cd} \times LHV}$$

Where w_{cv} is water vaporized in grams and ΔT is the change in temperature from start to boiling point