ASSESSMENT OF THE POTENTIAL ADOPTION OF LIQUEFIED PETROLEUM GAS FOR COOKING IN URBAN HOUSEHOLDS AND INSTITUTIONS IN MALAWI

MASTER OF PHILOSOPHY IN APPLIED SCIENCE (RENEWABLE ENERGY) THESIS

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(BSc Renewable Energy Technologies)

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THE POLYTECHNIC

OCTOBER 2021

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MASTER OF PHILOSOPHY IN APPLIED SCIENCE (RENEWABLE ENERGY) THESIS

By

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A Thesis Submitted to the Department of Physics and Biochemical Sciences, Faculty of Applied Sciences, in Partial Fulfillment of the Requirements for the Award of a Degree of Master of Philosophy in Applied Sciences (Renewable Energy).

University of Malawi

The Polytechnic

October 2021

DECLARATION

I, Admore Chiumia, declare that this is my work and that the use of materials from other sources has been fully acknowledged. This work has never been presented before for any degree or similar award to this university or any other university. I am responsible for the entire research, and no one mentioned in the acknowledgements bears any direct responsibility for this work.

Signature: ……………………………………………………………

Date: ……………………………………………………………

CERTIFICATE OF APPROVAL

We hereby declare that this proposal is the student's own effort, and it has been submitted this day with our approval.

Main Supervisor: Dr Adamson Thengolose

Signature: ……………………………………

Date: ……………………………………

Co-Supervisor: Dr David Tembo

Signature: ……………………………………

Date: ……………………………………

DEDICATION

I dedicate this work to the entire Lowosi (Chiumia) family, my work mates at Practical Action, Green Impact Technologies and friends for their encouragement, financial and moral support.

God Bless you all.

ACKNOWLEDGEMENTS

I acknowledge the hand of God Almighty for all the opportunities I have encountered throughout my lifetime.

My special thanks to my supervisors **Dr Adamson Thengolose** and **Dr David Tembo** for their constructive criticisms, excellent supervision, and guidance during the compilation of this dissertation. Your inputs made this research work more distinctive and educative and one of the great achievements of my life.

I also extend my appreciation to all Lecturers from Infrastructure Development and Management, postgraduate coordination team and the entire department of applied science at the University of Malawi Polytechnic for imparting the necessary knowledge which has shaped me to become a knowledgeable renewable energy practitioner.

I am indebted to the Malawi University of Science and Technology for permission to use their laboratory and all associated equipment for the research. My sincere thanks should also go to the Energy Affairs Department, Malawi Energy Regulatory Authority, Department of Forestry and Gas players for permission to be interviewed during the research.

ABSTRACT

More than 96% of Malawians relied on wood fuels (firewood and charcoal) for cooking and heating in 2018. About 4 million people in the country now use charcoal for cooking in urban areas which; has led to loss of forests resulting into increased run off, siltation of rivers and consequently depletion of water resources in lakes and rivers in Malawi. This research aimed to assess the potential adoption of Liquefied Petroleum Gas (LPG) as an alternative fuel to charcoal and firewood. Slovin's Formula was used to calculate sample size in which a total of 1200 households were interviewed. Further laboratory tests showed LPG as more efficient as a cooking fuel than electricity, charcoal, and firewood. Thermal efficiencies were recorded as LPG 68.1% (6kg LPG stove), electricity 56.2 (2kw hot plate), firewood 25.3%, improved firewood stove and Charcoal 23.2%, improved charcoal stove. The 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 the 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. The research highlighted limited knowledge of LPG efficiency and safety among potential users. These barriers to LPG uptake are compounded by the fact that LPG is perceived to be more expensive than other cooking fuels, there is less LPG supply, and the LPG distribution network is less developed than other cooking fuels. Despite these challenges, the market assessment revealed considerable potential for LPG market growth in Malawi, especially in urban areas where prices of charcoal continue to grow. intermittent electricity supply and low cost have proven to be key drivers of LPG demand. The researcher recommends that the Government of Malawi through MBS and MERA, facilitate harmonization of local and international standards of LPG gas handling and distribution to effectively support and regulate the sector. In conclusion to ensure Malawi's energy/environmental security, it is imperative that alternative cooking fuels (such as LPG) be promoted, incentivized, and adopted in Malawian household.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

CO	Carbon Monoxide
CO_2	Carbon Dioxide
ESCOM	Electricity Supply Corporation of Malawi
GoM	Government of Malawi
IEA	International Energy Agency
kWh	Kilowatt-Hour
LPG	Liquefied Petroleum Gas
MNREM	Ministry of Natural Resources, Energy and Mining
MBS	Malawi Bureau of Standards
SSA	Sub Saharan Africa
NCS	National Charcoal Strategy
NO_x	Nitrogen Oxide
NSO	National Statistical Office

CHAPTER 1: INTRODUCTION

1.0 Background

Energy poverty is a stark problem in most developing countries. The number of people using biomass for cooking is very high in most urban and rural households despite efforts done by most developing countries to increase access to electricity through grid extension (Widijantoro & Windarti, 2019). 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 (NSO, 2018) are not connected to the national electricity grid (ESCOM, 2016) and instead rely on dry cells for operating appliances, candles for lighting their homes and use of diesel for agricultural processing food. Access to electricity (%age of people with access to electricity) in Malawi was reported at 10 % in 2016 (Bilotta & Colantoni, 2019a) In rural communities only 5% is electrified which means majority of Malawians are still in darkness (Power Africa, 2018).

Malawi is currently facing major power shortages due to inadequate power generation, transmission, and distribution capacity. This condition has led to continued power rationing and persistent blackouts. The current installed generation capacity stands at 287 MW against an estimated demand of over 300 MW (Government of Malawi, 2019). In recent years hydropower has been greatly developed in most developing countries; however, in Malawi water resources are in short supply despite having 95% contribution to the energy mix (Arroyo & Miguel, 2019). The growth in demand for power is mainly attributed to industrialization, increased residential connections as well as increased agricultural productivity through increased pump fed irrigation. On the supply side, no major system expansion projects to support the increasing demand have been undertaken in the recent times except for the transmission system expansion and rehabilitation of Nkula power station funded by the Millennium Challenge Account.

Under development of alternative energy sources in Malawi retards transition from biomass fuels and remains a major barrier to controlling illegal charcoal production (Sepp, 2014). Electricity, the most obvious alternative, has a penetration rate of 2.0% nationally as a primary cooking fuel. This penetration rate is indicative of electricity's price and availability. Available electricity falls well short of present demand, and has become less reliable over the past five years (Ministry of Natural Resources and Climate change, 2017).

Cooking and heating fuel alternatives to charcoal, firewood and electricity (including LPG, biogas, briquettes and pellets, paraffin and solar) collectively are used by less than 1% of households

(Government of Malawi, 2017). This means that biomass fuels, including charcoal, will remain a dominant part of the energy mix for cooking well into the future (Department of Energy, 2016). Issues of energy security go beyond challenges of quantity and quality to broader issues of energy services that provide for broader social wellbeing, including nutrition and gender equality. For instance, energy insecurity in the form of cooking-energy shortages and/or high prices can undermine nutrition (Government of Malawi, 2019)(, food security and health (e.g., under nutrition and malnutrition among children under five years of age) by favoring fast-cooking over slower-cooking food (i.e., eliminating longer cooking more nutritious foods such as beans), or may lead to fewer cooked meals per day.

Unregulated production of charcoal and firewood from indigenous forests, coupled with inefficient consumption of charcoal and firewood, present significant development challenges that will impact Malawi in the near and medium-terms (Sola et al., 2019). First, demand will outpace supply by 2030, meaning there will be insufficient trees in Malawi to meet the charcoal and firewood demand from Malawi's population beyond 2030 (Ministry of Natural Resources and Climate change, 2017). Second, as wood supply continues to decrease (and as near-urban wood supplies become depleted, and transportation costs increase) the price of charcoal and firewood will continue to increase. The price increase will impact everyone who buys charcoal and firewood, the economic hardship will be most impactful on poorer urban residents. Third, heavy reliance on charcoal will continue driving deforestation and forest degradation which negatively impacts: agricultural production and food security; water quantity and quality (for consumptive and productive uses, as well as downstream hydroelectric production); and vulnerability to climate change. Fourth, as indicated in the (Blankenship & Urpelainen, 2019). Household air pollution from charcoal and firewood is the leading health risk factor for respiratory illness, and most significantly impacts women and children (pneumonia is the leading cause of death for children under five years of age in Malawi, and is one of the leading causes of morbidity(Government of Malawi, 2019). Ronzi et al. (2019) reports over 2.6 million people die every year due to exposure to smoke related diseases.

The ever-increasing power demand is exerting tremendous pressure on the existing power infrastructure to the extent that most businesses and residential premises have resorted to putting up diesel generators and other forms of generation to hedge against the negative impacts of frequent power cuts (Dalaba et al., 2018). The actual demand for petroleum products by current users in the country is important to inform proper planning and implementation of fuel storage facilities to cover the supply gap.

Almost every Malawian household—more than 97% of the population—relies on firewood or charcoal (biomass energy) to meet their household cooking fuel needs (National Statistical Office Malawi, 2018). Furthermore, charcoal production improves livelihood in communities however if not controlled adverse effects will occur to the environment (Kiruki et al., 2020). While firewood remains the most widely used cooking fuel in Malawi (87.7% in 2014), the %age of Malawian's using charcoal as their primary cooking fuel grew significantly from 2% in 1998 to 11.3% in 2014 (National Statistical Office Malawi, 2015). 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 adoption of alternative cooking fuels (Van Hoeven et al., 2017) such as Liquefied Petroleum Gas (LPG) will provide households with alternative cooking sources otherwise the continued reliability of charcoal will lead to loss of forests cover which will impact Malawians in multiple ways, such as:

a) Declining availability of wood for firewood, timber, and poles
b) Decreasing water retention and soil fertility; and
c) Declining hydropower production.

1.1 Research Problem

Malawi's energy sector faces serious supply challenges which includes in sufficient power generation, lack of reliable investors to increase power generation, transmission and distribution of electricity this has led to most (89%) households rely on biomass for cooking (Zalengera et al., 2014). Malawi's demand for charcoal and firewood is increasing faster than the adoption of alternative energy sources. The 2018 Malawi National Statistics research revealed over 96% of Malawians use firewood or charcoal for cooking. Further, over the past 12 years, reliance on wood fuel has grown and population has also grown significantly increasing demand for wood fuel (IHS, 2018). This is driving forest cover loss, especially near urban areas. The demand will continue growing resulting in decreasing supply and loss of environmental services. The researcher further established that between 2011 and 2017 charcoal usage increased from 1 Million to 3 Million this means at the moment more Malawians use charcoal and firewood than it was in 2005researcherx.

If this is not addressed, urban charcoal demand will continue to grow, resulting in forests degradation increasing costs, and loss of environmental services.

To respond to the growing charcoal/energy problem, the Government of Malawi, led by the Departments of Forestry and Energy, have been leading a Task Force that developed a National Charcoal Strategy (NCS). The goal of the NCS is to provide a framework to address the linked problems of increased deforestation and growing demand for household cooking fuel. As part of the NCS work to-date, the Task Force conducted a "rapid scan" of alternative cooking fuels (including electricity, LPG, briquettes and pellets, paraffin, and biogas). The research suggests LPG holds the greatest potential for scaling-up adoption in urban Malawi. The adoption of LPG as an alternative to charcoal for household cooking has achieved some degree of success in other Sub-Saharan African countries, but there are widely accepted common market barriers identified that have inhibited higher rates of adoption in many countries (K. Sharma & Ahmed, 2018). These market barriers include factors related to accessibility, cost, and limited awareness of the value, use, sources and perceptions on the safety of LPG (Kiruki et al., 2020). This triggered the researcher to assess the adoption of LPG in urban households who are the major charcoal consumers as an alternative source for cooking.

1.2 Research objective

The main objective of this research was to assess the potential adoption of LPG as an alternative cooking fuel for urban households in Malawi.

1.2.1 Specific Objectives

1. To assess the willingness to pay and private sector investment across the LPG value chain in Malawi
2. To assess household's preferences on available cooking fuel alternatives (electricity, charcoal, firewood,) comparative to LPG

To deduce the efficiency of LPG as compared to other available cooking fuel alternatives (electricity, charcoal, firewood,) in Malawi.

CHAPTER 2: LITERATURE REVIEW

This chapter will discuss research works on the market potential for Liquefied Petroleum Gas (LPG) on global, regional and country (Malawi) level. The review involved researching existing LPG reports and policy documents, LPG market assessments and articles or other academic research papers. Special attention was given to 2014 to current reports have been published to ensure relevance and reliability of the information gathered. The literature review encompasses the keys concepts that informed the research, the theoretical framework, the main conclusions from the sources and summaries integrating the researcher's reading. The information included herein referenced back to its source in the references section of this thesis.

2.1 Description of Liquefied Petroleum Gas

A paper published by GIZ (2014) under the Poverty-oriented Basic Energy Services (HERA) program reported Liquefied Petroleum Gas being 60 % by-product of natural gas extraction and 40 % crude oil refining. It is further described LPG as a fossil fuel that is a mixture of hydrocarbon gases (flammable) and does not occur in isolation (Farabi-Asl et al., 2019). The gases that fall under the "LPG" label include ethane, ethylene, propane, propylene, normal butane, butylene, isobutane and isobutylene, as well as mixtures of these gases and that the two most common gases are butane and propane (Embiale et al., 2019)

2.1.1 Uses and benefits of using Liquefied Petroleum Gas (LPG)

According to a report by the Competition Commission of South Africa (2017), LPG is used by the following categories of end-users: Residential Users, Industrial Users, Commercial Users, Auto gas Users. In the agriculture sector, LPG can be used for crop and produce drying, greenhouses heating, hot water for dairies, Irrigation pumps and heating animal enclosures (Dalaba et al., 2018). According to Shell (2015), LPG can be used for non-energy or material purposes as a propellant or coolant or as feedstock in the petrochemical industry.

According to Shell 2015**,** LPG often offers technical, ecological or economic advantages over alternative substances. Yip et al. (2017)**,** points out that LPG cook stoves heat quickly, and provide considerable control over the desired level of cooking power, so users can benefit from time savings through faster cooking. A switch to LPG could therefore bring about a significant reduction in indoor air pollution since it reduces health-adverse exposures in comparison to open fires or traditional stoves (Carrión et al., 2018). This alternative cooking fuel would therefore be a better option for urban households in Malawi who are currently using charcoal for cooking.

From an environmental point of view, LPG usage contributes to reductions of greenhouse gas emissions in many countries where most inhabitants still use wood or charcoal fuels (Murshed, 2018). For instance, households that cook with charcoal emit 5 to 16 times more greenhouse gases per meal than those using LPG (Berko, 2018). Substitution through LPG can considerably reduce overall wood fuel consumption in a country or region (Dalberg, 2013). A mere 45kg of LPG are sufficient for replacing the thermal energy of 1 tonne of wood used to produce charcoal with traditional stove technologies (Mangula et al., 2019). Moreover, an entire hectare of savannah forest is needed for the sustainable wood production of 1 tonne of firewood (GIZ, 2014). LPG can reach isolated areas without significant infrastructure investments, can be stored safely, and can provide the basic services for the neediest, such as heating, cooking, and lighting, (Lucon et al., 2004).

2.1.2 LPG Equipment and Safety Issues

According to (GIZ, 2014) a typical LPG cooking system consists of a steel cylinder, a pressure regulator, a hose connecting the regulator to a burner and the burner itself. Potential safety problems can arise from leaking equipment or improperly storing and handling LPG. LPG stoves have an efficiency rate of between 55% to 60%; cost around 30 USD to 60 USD and have an expected lifetime of 5 to 8 years (GIZ, 2014). LPG is typically supplied in cylinders of various sizes: 2.7 kg, 6 kg, 12 kg, 16 kg or up to 47.2 kg. A research by (Hossain et al., 2019a) found that in a sample of 20 countries, the most commonly used cylinder sizes were 6 kg or smaller. This might be because smaller cylinders are cheaper and more portable so most consumers could easily adopt.

2.1.3 Supply Chain of LPG

An efficient supply of LPG plays a very important role in the adoption of LPG (Steuer, 2019). In the Ashanti Region of Ghana, technical and transportation disruptions were ranked by retailers and consumers as major factors that disrupt the supply of LPG (Asamoah et al., 2012). Once purchased, the LPG is delivered to bulk distribution depots and cylinder-filling plants – some of which are combined at large sites – by means of wide-load road tankers, ships or railcars (Hart, 2017). From these distribution depots or sites, smaller delivery tankers bring deliveries to domestic customers. Supplies to the end user are organized through specialized shops, general dealers or filling stations.

Extracted from SHV energy. The organized supply chain would enhance the adoption in the context Malawi where the distributers do not provide transportation of cylinders to their customers (Fig.1).

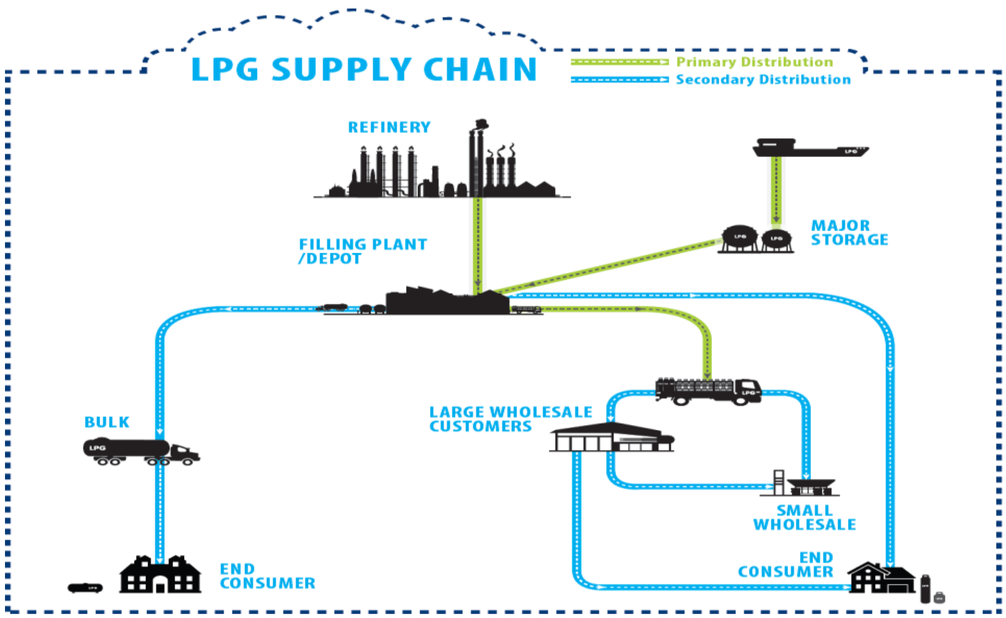


Figure 1: LPG Supply Chain. Source: Hossain et al. (2019**)**

2.2. Global perspective of the LPG Industry

LPG production growth remains strong in the US and Canada, but other regions are also growing quickly, and most global LPG growth is driven by only a few regions that already have more LPG than they need. Global LPG demand growth will continue to be led by Asia and the Middle East (Gioda, 2019). Roughly, half of the global LPG demand is in five countries United States of America, Saudi Arabia, China, Japan, and India. Residential/commercial LPG demand is growing steadily (Akowuah, 2019). China and India are the major drivers of global residential and commercial demand growth (Hart, 2017).

Replacing traditional biomass or solid fuels with LPG has been the focus of international aid programs (Ravindra et al., 2019). LPG, however, is an oil derivative and is thus affected by rising and volatile crude oil prices (Kemausuor & Adaramola, 2018).

2.2.1 Consumption and Production of LPG

Globally 281 million tonnes of LPG were produced in 2013 against a demand of around 268 million tonnes of which around 123 million tonnes were used for cooking and heating (Hutagalun et al., 2019). LPG is the least utilized of the four major cooking fuels: firewood, kerosene, charcoal, gas

(Van Leeuwen et al., 2017). Two thirds of the LPG demand in Sub Saharan Africa (SSA) is in seven countries namely Angola, Ghana, Ivory Coast, Kenya, Nigeria, Senegal and Sudan whereas just under half of regional demand occurs in West African countries (Chikezie et al., 2020)

2.2.2 Operating Environment

Africa has significant future energy challenges (Arroyo & Miguel, 2019) and gas can address many of them now. Opportunities for gas development would start with LPG. To thrive the LPG industry in Africa needs proper regulation, enforcement and investment (Taher, 2019). The global LPG partnership seeks to mobilize financial investments and policy reforms to support consumer finance and education in five SSA countries of Kenya, Cameron, Tanzania, Ghana and Uganda (Dalberg, 2013).

The largest African consumer markets for LPG are in North Africa. The annual LPG consumption rate per capital in Sub-Saharan Africa is 2.3 kilogram (kg) compared to 55 kg per capita annual consumption in North Africa (Nkalu et al., 2020). The largest LPG markets in SSA, per capita annual utilization in kg is Senegal (10.1 kg), Ivory Coast (8.6 kg), Angola (7.8 kg), South Africa (5.7 kg), Ghana (5.4 kg) and Sudan (5.3 kg) (Ranjan, 2019). The higher utilization of LPG in these countries is due to long-term government support and subsidies. However, some of the biggest constraints to the growth of the LPG markets are supply deficits owing to low and erratic production capacity of refineries and increased cost for LPG resulting from inadequate transport, distribution, and storage infrastructure (Asamoah et al., 2012).

In Malawi, there has been significant year on year growth of LPG importation from 200,000 to 900,000 kgs since 2013. The main suppliers of LPG in Malawi are currently Afrox and Delta Gas. Based on best available information, this research estimates total household utilization of LPG to be 0.4% in Malawi (Van Leeuwen et al., 2017). Much like the case in the rest of Sub-Saharan Arica, LPG consumption in Malawi is largely amongst middle to high-income urban households. Typically, LPG users in Malawi previously used electricity as their primary means for cooking supported by charcoal, and often switch to LPG due to the erratic supply and/or increasing cost of electricity.

LPG is one of the most promising alternatives to urban charcoal use in the medium and long term. However, affordability, accessibility and acceptability of LPG are key variables that determine adoption(Ministry of Natural Resources and Climate change, 2017). All three of these variables must be clear to the potential customer otherwise adoption will remain limited.

Affordability: MERA recommends the retail price of LPG per kg, as of March 2020, the cost was MK 1744.74, significantly higher than the global average price of $0.63 USD per kg[1], and marked up significantly from the South African Freight on Board price of 10.69 Rand (Malawi Energy Regulatory Authority, 2020). Affordability itself has numerous drivers including LPG regulation, proximity of Malawi from the LPG source and resulting transport costs, storage, last mile distribution, market acceptability and understanding of use. When considering perceived (accurate and inaccurate) cost of viable alternatives, it is important to note the comparison is often made with charcoal prices. The financial cost of charcoal has an upward trajectory, which is anticipated to continue due to large and increasing demand for charcoal and limited supply of biomass to produce charcoal. Furthermore, LPG in Malawi is extremely expensive relative to the global average and has potential to decrease with greater volume of LPG sales.

Accessibility: LPG safety regulation in Africa follows a European standard which is generally higher than that of South America and Asia. While this is good for maintaining safe use of LPG, it makes LPG even more expensive and accessibility limited. Regional gas storage facilities are important for ensuring safe storage of large amounts of LPG for easy onward transmission to the consumer. Shorter distances from the storage facility to consumer's home is needed to create a denser network of distributors and consequently, users. The LPG value chain is complicated in any market, but in an underexploited market such as Malawi, there are limitations on accessibility that are a function of storage and distribution, both of which limit supply because of the high storage costs and limited LPG supply from gas producers. LPG suppliers need to supply at significant volumes to reduce cost.

Acceptability: the knowledge and understanding of LPG in Malawi remains low. A research by Practical Action Consulting highlighted limited knowledge of LPG efficiency and safety among potential users (Borgstein et al., 2019). Perceptions that LPG is unsafe and more expensive than other cooking fuels further hamper uptake.

It is evident that Malawi LPG sector could thrive if more incentives are introduced through private sector engagement and subsidies would trigger the uptake and develop the consumption culture at entry level.

2.3 Review of LPG uptake in other countries

2.3.1 India

According to Chaurasia, (2018) marketing of LPG in India started in the 1950s, and is the fourth largest consumer of LPG overall in the world and the third largest domestic consumer among the developing countries (Sharma, 2019). The following regulatory influence is in force to promote the use of LPG in India:

i. **Rural Market:** Focused approach by the Government of India to increase penetration of LPG in Rural Areas through the following strategies: deposit free connections, low-cost distribution models.

ii. **Industrial or commercial segment:** creating awareness about LPG as cleaner fuel, capital investment in industries for LPG installations, strict pollution control and FDI in retail sector.

iii. **Pricing of LPG:** Pricing based on import parity price, market driven prices for commercial and industrial LPGs, subsidy for domestic LPG by the Government of India.

2.3.2 Saudi Arabia

Saudi Arabia is also one of the top exporters of LPG, but these exports are also predicted to decline in the future (Coady et al., 2019). LPG consumption is forecasted to increase from 604.4 thousand bbl/d in 2014 to 831.9 thousand bbl/d in 2023 (Zothantluangi, 2018). Even though the LPG supply is expected to grow along with the LPG demand, the growth in supply is predicted to be lower than that of demand (Hart, 2017). Thus, a significant downward pressure is expected to be put on Saudi Arabia's exports of LPG.

2.3.3 Japan

According to the Current State of Japan's LP Gas Industry (Halder & Gupta, 2019), Japan's current LPG demand is approximately 14million tonnes. The demand for residential and commercial use accounts for 44% while Industrial and chemical feedstock around 20% each (Jingjit & Techato, 2020). Gross demand has been declining after reaching its peak of 19.70million tons in 1996. In particular, the demand for residential/commercial use had declined (Farabi-Asl et al., 2019).
To address the challenges, Japan intends to do the following:

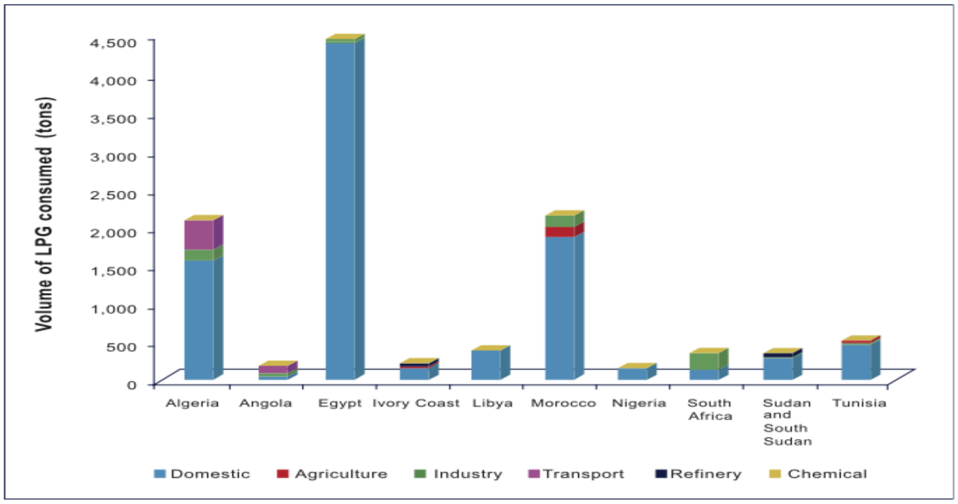
i. Create demand (especially for residential/commercial use through the following means: Making the retail price inexpensive by promoting transparency of pricing, making import price inexpensive by diversifying suppliers. Approximately 80% of Japan's LPG relies on imports (Ali et al., 2019).
ii. Strengthen the foundation of the LPG Industry by meeting the world's strictest safety standards and by conducting a market research in Vietnam and Myanmar and establish forum for dialogue at the private sector and the government levels, support the broader LPG use in the South East Asian Countries where the increase in demand is expected.

2.4 LPG use from other countries in Africa

According to the United Nations, Sub-Saharan Africa (SSA) comprises all the countries that lie fully or partially to the south of the Sahara Desert (Schure & Pinta, 2019). At 82 % compared to 40 % globally, SSA has the highest dependent on solid fuels (comprising mainly wood and charcoal) among the developing countries (Simkovich et al., 2019). At 18 %, a small proportion of the population relies, comprises mainly urban and middle-income consumers, on modern forms of energy as such kerosene deduced at 7 %; LPG at 5 % and electricity at 6 % (Chakraborty, 2019). However, the reliance on solid fuels for the rural population at 94 % is much higher than that for the urban population at population at 64 % (Udesen, 2019).

Southern Africa has the lowest proportion of the population at 56 % relying on solid fuel as compared to 28 %, 10 % and 7 % for electricity, LPG and kerosene respectively (Karanja & Gasparatos, 2019). Global LPG Partnerships' (GLPGP) targets 70 million new users of LPG by 2018 and the Africa Biogas Partnership's targets biogas access for 10 million people by 2020. After such cleaner energy initiatives are implemented, the reliance on solid fuels in the SSA would still be significantly higher than it is today (Champion & Grieshop, 2019). It is estimated that the population of Africa using solid fuels as primary source of energy will reach 750 – 800 million people by 2020 (Twerefou et al., 2018).

The figure 2 below shows LPG consumption by sector in the top ten African countries with domestic consumption ranking the highest and seconded by the industry sector in most countries.



Source: Argus Statistical Review of Global LP Gas 2014

Figure 2 : LPG consumption by sector by the top ten African Countries

2.4.1 Characteristics of LPG Market in Sub-Saharan Africa

The LPG supply chain, normally including actors such as producers, distributors, retailers, customers and service providers who play different roles in the supply chain, is a means through which LPG is delivered to consumers (Ronzi et al., 2019). LPG supply begins with the producers - the oil and gas industry. Marketers may be oil or gas company affiliates or independent businesses whose scale of operation may range from local to multi-national (Bruce et al., 2018). LPG moves from the point of production to the ultimate user in a sophisticated transportation and distribution system (Kasangana & Masekameni, 2019).

Household appliances are generally available in a range of sizes and qualities (Mliswa et al., 2019). They are imported or manufactured in commercial plants or, at lower prices, in local craft shops (Geographers, 2018). Appliances manufactured in local craft shops are relatively inexpensive for buyers whose income is on the lowest end of the economic spectrum (Hossain et al., 2019b)**.** Error! Reference source not found. below shows a typical LPG value chain in South Africa.

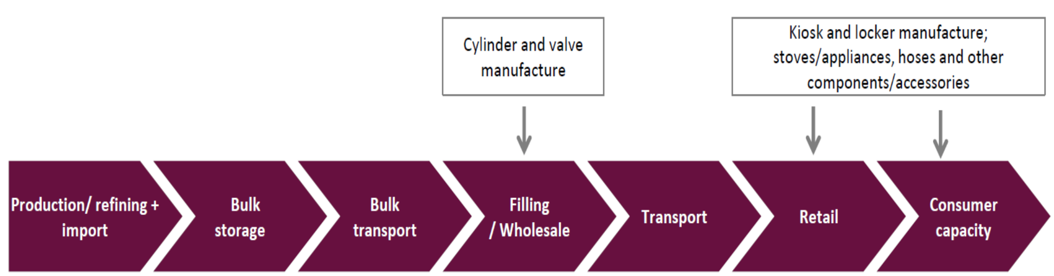


Figure 3: Typical LPG Value Chain (adapted from GLPGP, 2013)

LPG is either produced locally where a country has oil refineries or/ and imported to supplement local production or where none is produced locally (Asamoah et al., 2012). LPG producing and importing companies are ether wholly state owned, wholly privately owned or state and privately owned (Murshed, 2018). At the wholesale depots LPG is filled in cylinders of different sizes (for example in Kenya, cylinders of 1kg, 3kg, 6kg and 13kg are used) where it is transported to retail outlets (mainly petrol filling stations and other supermarkets) from where consumers access the LPG (Dalberg, 2013).

LPG pricing varies from country to country based mainly on the value chain factors and relevant policies in place (Mouhoud, 2018). For example in 2015 the cost of LPG was US$705/tonne for Senegal with a fully liberalized market (LPG locally produced and imported) and 170 USD for Gambia with a regulated market (Van Leeuwen et al., 2017)**.**

2.4.2 Review of Sub-Saharan Africa LPG uptake

2.4.2.1 Kenya

Kenya has low LPG use considering that it is one of the economic hubs in the continent that promote initiatives for LPG utilization (Line, 2018). LPG consumption in Kenya at 5 % is just above the average LPG consumption for the SSA at 4 % (Bilotta & Colantoni, 2019). The highest consumption increase of LPG has been concentrated in the inner cities of Nairobi and Mombasa (Van Leeuwen et al., 2017). Increased charcoal use has been driven by low relative costs. In rural areas, firewood constitutes main fuel and has remained consistently so over time with ~ 75% of rural households exclusively gathering it rather than buying it (Gitau, et al. 2019). LPG use in rural areas has been consistently low, at under 1 %, because of inadequate LPG distribution and retail networks in rural areas and the high availability of cheap firewood (Sultane, 2018). It appears that increase in LPG use has been driven primarily by switch away from kerosene (kerosene use declined from 57% in 1999 to 21% in 2009 instead of switching from fuelwood (Jiang et al, 2019). The price for LPG in Kenya is one of the highest in the world as such the availability of cheap charcoal limits its adoption (Fan, 2019). Other factors limiting adoption of LPG are that storage, distribution and retail capacity are concentrated in the major urban centers of Nairobi and Mombasa (Sultane, 2018).

LPG prices in Kenya are significantly higher than global prices estimated at 2-3 times higher than in other developing countries (Mouhoud, 2018). High LPG costs in Kenya are mainly due to value chain constraints and low consumer affordability whereas in other (such as Senegal) lower costs are because of public action that lowered barriers to adoption (Fan, 2019). Although no value added tax (VAT) is charged on LPG, 25 % import tax is charged and 16 % VAT is charged on cylinders and appliances. In addition, LPG prices in Kenya are not regulated as such licensed LPG marketers are free to set their own prices resulting in overcharging. LPG market is regulated, by the Energy Regulatory Commission (ERC) and standards governed by Kenyan Bureau of Standards (KEBS), however in practice enforcement of regulation is weak (Ravindra et al., 2019). For example, although cylinder revalidation is required every 8 years, in practice it is required frequently but it is rarely done (Dalberg, 2013).

Limited distribution of filling stations/ depots outside Nairobi makes access difficulty and expensive resulting in illegal filling and cross-filling (Line, 2018). In 2012 illegal filling was estimated at 30 % up from 10 % 2-3 years earlier (Fan, 2019). Illegal filling is exacerbated by standardized valves and lax enforcement of regulations due to vested interest or political interference (Karanja & Gasparatos, 2019). Moreover, some marketers are unwilling to pay to take back their cylinders. In addition, storage and filling infrastructure and development of cylinder inventory very costly and working capital intensive (Van Leeuwen et al., 2017).

According to Van Leeuwen et al. (2017), various policy interventions and strategies have been used to improve access, ensure security of the supply of affordable energy (LPG in particular) and achieve efficiency and conservation (Table 1).

Ta**ble 1:** Strategies used to improve access to LPG **Country**	**Policy Issues**	**Policies Recommended**
Ghana	**Switching from charcoal to LPG**	A poor targeting subsidy on fuel/equipment having both an environment benefit (avoiding deforestation) and a basic need support for lower income groups

		Subsidies were on smaller LPG bottles/cylinders of 2.7 and 6kg LPG bottles. Increased reliability of LPG
Senegal	**Low LPG penetration**	Senegal adopted LPG as cooking fuel, increasing demand substantially Exempted modern fuel appliances from import duties Introduced direct fuel subsidies on LPG fuel cylinder funded by taxes on other petroleum products, and offering discounts on smaller units of LPG fuel.
Burkina Faso		Introduced forest taxes and levies to drive up the market price of firewood, which is the main fuel of choice for both rural and urban areas.
Tanzania		Uptake of LPG has been limited due to the unavailability of the fuel and equipment, but the introduction of tax reductions has improved situation. Providing direct subsidies to LPG, creations, and establishment of LPG market.

2.4.2.2 Senegal

Senegal is one of the few SSA countries where an LPG development programme has been successfully implemented (Murshed, 2018). The Senegal LPG programme managed to increase LPG consumption from 10–12 % (13,221 tonnes in 1985 to 140,000 Tonnes in 2005) to 90 % in Dakar, 60 % in secondary cities and 31 % in rural areas (Makonese & Ifegbesan, 2018). This puts Senegal with the highest % of the population using LPG as fuel in the SSA(Amorin et al., 2018). The government championed the program through political will and policy, technical and financial reforms in the LPG market (Bilotta & Colantoni, 2019b)**.** Specific elements of the program are described here.

- Introduced gas cylinders with a capacity of 2.75 kg in 1974 and then 6 kg cylinders in 1983 to ensure lower upfront cost (Inge, 2018). This enabled more low-income households to gain access to LPG;

- Liberalized the importation of LPG thereby increasing competition amongst importers (Kennedy et al., 2019);
- Removed taxes initially levied on imported equipment and introduced differential pricing structure taking into account different income groups to promote LPG among low-income communities (Kluschke et al., 2019).
- Implemented subsidies for LPG and LPG equipment from the 1970s which were gradually reduced in portions of 20 %, beginning in 1988 and were planned to be completely eliminated by mid-2002 as at this stage more people had knowledge of LPG and demand had been created (Pilavachi et al., 2009).
- Regulated charcoal production and marketing (Krause, 2019). Quotas on the exploitation of forest resources for charcoal production to control charcoal production were enacted. Wood cutting license fees were raised; extraction quotas and land allocation system for charcoal production were revised (Carrión et al., 2018). In addition, the Government imposed a higher price on charcoal.
- Increased the number of LPG refilling centers in the remote areas to increase access and utilization (Karanja & Gasparatos, 2019).

Table 2: Strategies by Government of Senegal to promote LPG

Notable project achievements	Increased LPG consumption from 10–12 % (13,221 Tonnes in 1985, 14,000 Tonnes in 2005) to 90 % in Dakar, 60 % in secondary cities and 31 % in rural areas
Key benefits	Reduction of deforestation of up to 45,000 hectares per annum. LPG gas enhances the health of the women and the children by reducing exposure to indoor air smoke from biomass cook stoves. Women and girls are freed from collection of firewood thereby having more time undertake income generation activities and researching respectively.
Key drawbacks	High cost of subsidies to maintain LPG at a price competitive with charcoal
Key factors that led to success	Long term commitment by the government. Specialized focus on LPG. Building on existing networks. Increased opportunities for income generation in cylinder manufacturing and gas distribution,

Local champion: Government of Senegal.

These findings indicate that enabling policy can result in increased access and utilization of LPG. Malawi can therefore learn lessons from the LPG program in Senegal to implement its own LPG program so that households that are currently using charcoal can shift to LPG as their core source of energy for cooking.

2.4.2.3 Ghana

The overexploitation of forest and its implications such as desertification has seen Ghana adopting a proactive policy towards the development of LPG (Mliswa et al., 2019). The government in 1990 launched the National LPG Program and the Tema Oil Refinery was drafted into the production of LPG in the country (Broni-bediako & Amorin, 2018). A campaign was subsequently launched in the country with the aim to get urban households, public institutions requiring mass catering facilities and the informal commercial sector including small-scale food sellers to patronize the use of LPG as alternative to charcoal and firewood (Kemausour et.al., 2011). LPG consumption doubled in 1992 and by 2004 consumption had increased to more than 65,000 tonnes per year from nearly 45,000 tonnes in 2000 (Kennedy et al., 2019). By 2007 consumption had reached more than 103,000 tonnes (Van Leeuwen et al., 2017). A network of LPG filling stations exists in Ghana with most of them concentrated in and around Accra.

In 2003, there were 98 LPG filling stations in Ghana of which 64 were in the Greater Accra region with Upper East and Upper West Regions having only one station each (Chikezie et al., 2020). Thus, the distribution of LPG filling stations was skewed in favour of Greater Accra and Ashanti region (Kemausour et al., 2011). Bridging the access gap by embarking on a rapid scale up of LPG access interventions and improved safety environment is essential for catalyzing “LPG market take off” in Ghana (Edjekumhene, 2007).

The domestic LPG production in Ghana is limited and imports account for most of the total supply to the market (Krause, 2019). The continuous absence of LPG in the market would therefore be a recipe for both domestic and commercial users of the product to revert to the use of electricity, charcoal, and firewood hence the need to ensure that disruptions in the supply of the LPG are reduced to an acceptable minimum level (Samoah, 2012).

A study by Samoah (2012), further found out that technical disruption ranked highest amongst consumers. Consumers ranked financial, transport, political, location and natural happenings as the second through sixth most significant disruptions in the supply chain of LPG respectively. Transport was considered the second most predominant supply chain disruption among the retailers, which was attributed to the long distance from the source of LPG, which adds uncertainty to supply continuity through longer lead times. Financial and natural happening had equal weights whilst location and political disruptions were ranked lowest. The most prominent strategy by both retailers and consumers to reduce LPG shortages is by placing orders for the product early.

The government is in the process of revising its LPG Policy to increase LPG penetration to 50% by 2020 (Gas Master Plan 2016). According to the Energy Commission, Ghana, estimates that the total national LPG requirement for 2015 to be within 300,000 and 350,000 tonnes due to the growing demand, particularly as transport fuel. Though the ministry is targeting 50% penetration by 2016, it was not likely to be achieved due to limited distribution outlets nationwide. This can however be achieved by implementing the measure to support and accelerate the supply and use of LPG outlined in the Energy Sector Strategy and 2010 development Plan and the 2010 LPG Policy Paper, which include:

- Deliberate government policy to make the LPG produced available for local consumption as against export
- Removal of price distortions
- Recapitalizing Ghana Cylinder Manufacturing Company (GCMC) to expand production capacity with the production of cylinders focused on small sized cylinders that would be portable and affordable to households in rural communities.
- Constructing LPG storage and supply infrastructure in all regional and district capitals in the long term and to develop district capital LPG infrastructure in the medium term

2.4.2.4 Mozambique

Modern fuels can also improve the delivery of health services, by providing lighting and refrigeration in places where it is difficult to ensure reliable electricity and as an alternative to kerosene (Hannan et al., 2018). In northern Mozambique, Vida Gas supply of LPG to health clinics has contributed to a 36% increase in the number of children immunized in participating districts, and to Mozambique’s national targets for maternal and child health (Sultane, 2018).

Mozambique has no specific legislation governing the storage, bottling, handling, distribution, and use of LPG (Hossain et al., 2019a). The industrial sector account for only about 10% of the total consumption (Chiteculo et al., 2018). Based on the growth rate over the past few years, it was probable that the demand for LPG could double over the next 5 years (Sprague & Woolman, 2011). The main barriers to LPG adoption in Mozambique (Bilotta & Colantoni, 2019) include:

A. Demand for LPG

- Ineffective marketing strategies
- Strong preference from customers for charcoal
- Current distribution systems that do not reach BoP
- Financial constraints

B. Supply for LPG

- Price cap which limits investments in the medium and long term
- Lack of infrastructure
- Supply constraints from South Africa
- Natural Gas piping may be seen as fulfilling the role of LPG.

2.4.2.5 South Africa

The production and supply of LPG in South Africa involves many players in the value chain, including the refineries/producers, wholesalers, distributors, dealers, retailers, and end users (Department of Energy, 2016) as presented in figure 4 below

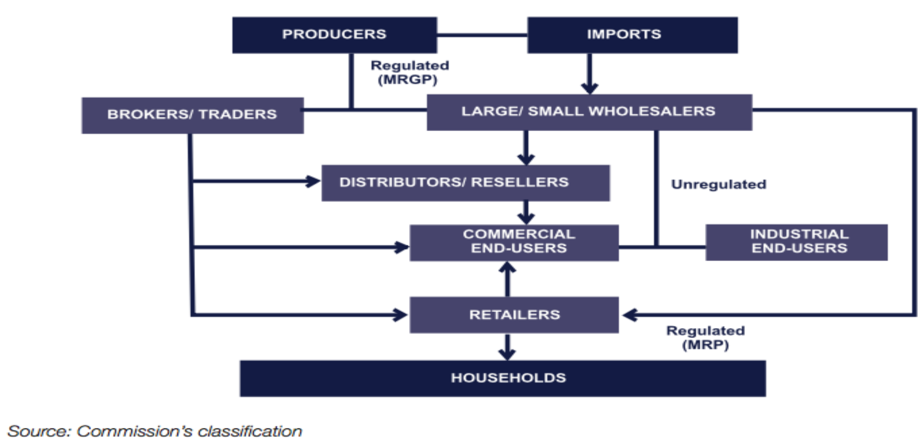


Figure 4:The supply chain of LPG in South Africa. Source?

The main LPG players like Easigas (pty) Ltd, Oryx Oil South Africa (Pty) Ltd, Totalgaz Southern Africa (Pty) Ltd, Africa Oxygen Ltd and Wasaa Gases (Pty) Ltd are some of the LPG wholesalers in South Africa (Kock, 2017). Compared to other developing countries, South Africa still has a large potential for increasing the role of LPG in its energy mix (Tinarwo & Gitari, 2018). In this context, the Department of Energy (DoE) is working with the industry to develop the market and the regulations related to the pricing of LPG, including several other objectives to promote the shift toward increased gas and LPG consumption as listed in the Gas Act, 2001 (Act No. 48 of 2001) (Kasangana & Masekameni, 2019). These objectives include the following:

- Facilitating investment in the gas industry
- Ensuring the safe, efficient, economic, and environmentally responsible transmission, distribution, storage, liquefaction, and regasification of gas
- Promoting companies in the gas industry which are owned or controlled by historically disadvantaged South African by means of license conditions to enable them to become competitive
- Promoting skills development among employees in the gas industry
- Promoting the development of a competitive markets for gas and gas services
- Promoting access to gas in an affordable and safer manner.

Currently, the DoE of South Africa is aware of the pricing structure challenge in terms of the Maximum Refinery Gate Price (MRGP) of LPG, which means the highest cost fuel alternative to the consumer (Ronzi et al., 2019). An unintended consequence of the current MRGP is that the reduction of the selling price relative to the price of octane petrol, makes the refining margin on producing LPG negative (Hossain et al., 2019). During the 2016/17 financial years, the DoE was working on rectifying this aspect of the LPG market in consultation with relative stakeholders through the development of the 20- year Liquid Fuels Master Plan (Huxham & Nelson, 2019). The Competition Commission, 2017**,** found that importing larger parcels of LPG would result in the landed import price being lower than the MRGP and that to encourage the sustainable supply of LPG throughout the year, the focus of this sector should be on larger import and storage facilities (Klausbruckner, 2018).

The petroleum products supply situation in the country remains very tight, especially with regard to Liquefied Petroleum Gas (LPG). LPG supply constraints were more acute in 2015 due to the product shortages (South Africa Petroleum Industry Association (Africa, 2018). The main objective of SAPIA is to facilitate LPG imports to unlock supply and to position LPG as a real alternative solution. Due to safety concerns that communities have, SAPIA has engaged the LP Gas Safety Association to assist in developing awareness about the safe usage of LPG (Mohlakoana

& Annecke, 2009)(. According to the Izzaty et al., (2016) the Department of Labour mandated the South African Qualification and Certification Committee for Gas (SAQCC) to ensure all gas practitioners are trained and certified through the four different gas associations namely:

i. Liquefied Petroleum Gas Safety Association of South Africa (LPGASASA)
ii. Southern Africa Compressed Gases Association (SACGA)
iii. Southern African Refrigeration and Air Conditioning Contractors Association (SARACCA)
iv. Southern African Gas Association (SAGA)

Table 3: Challenges faced in South African LPG Sector

#	Challenges	Solutions
1	Illegal Cylinder Acquisition Cross border migration of exchange/deposit based cylinders Leads to lack of maintenance of LPG cylinders	Proper recognition of cylinder ownership with regulations Tight control at country borders. Regular monitoring and inspection throughout the distribution chain. Cooperating with regulatory authorities.
2	Illegal filling of cylinders Under filling of cylinder (Trade Metrology Regulations) Overfilling of cylinder (high safety risk)	Monitoring and auditing of the distribution chain Regular inspections of calibration of weighing equipment. Registration of filling personnel in in terms of the pressure equipment regulations. Licensing of LPG filling sites in terms of the Petroleum Product Act. Regular training and skill development on proper filling procedures by the LPG industry
3	Illegal installation Injury and damage to property	Requirement for the registration of LPG installers, under SAQCCA Gas Requirement for the issuing of a Certificate of Conformity (CoC) after completion of a Gas installation. Regular inspections of installers Installer Code of Good Practice

		Disciplinary action for non-compliance.
4	Illegal appliances and equipment Injury and damage to property	Requirement for verification of LPG Equipment and Appliances LPSASA Safe Appliance Scheme (under the Department of Labour) Inspection and monitoring Industry participation Enforcement and prohibition (LPGSASA and Department of Labor)
5	Over storage of cylinder Pose a huge danger to people and facilities	Proper designation of storage areas Regular on site monitoring.
6	Proliferation of illegal retailers Leads to illegal retailers filling cylinders without permission Leads to lack of maintenance of cylinders Unsafe environment	Licensing of LPG retail and filling sites Business development and start-up funding Compliance and monitoring Enforcement
7	Lack of citizen safety education Education on safe use of LPG and other sources of energy is lacking Fear of using cleaner more efficient products Potential misuse of LPG due to lack of understanding	Review of school curriculum to add household safety Household safety programs Participation by all key role players to communicate the safe use of LPG. Public broadcaster to assist in promoting household safety and use of LPG.

2.5 Malawi LPG perspective

Government of Malawi (GoM) in the 2018 Energy Policy states that it shall promote Liquefied Petroleum Gas (LPG), Biogas and Natural Gas as more sustainable and convenient energy options for process heat. The policy further states that GoM shall implement programs aimed at building the capacity of the LPG, Biogas and Natural Gas Industry. In the medium to long term, Liquefied

Petroleum Gas (LPG) and natural gas must be an important part of the energy mix because women's reliance on process heat for care giving and value addition means that although they value electricity for lighting, this source of energy (coupled with its high costs) is not the most practical for their cooking/heating needs.

To support the policy direction Government has taken on LPG, The Malawi Energy Regulatory Authority (MERA) developed a robust regulatory framework in 2017 for the LPG supply chain covering licensing requirements and procedures, safety regulation in transporting, distributing, storage, handling and consumption of LPG, inspection and monitoring of supply chain for enforcement of standards, and incident reporting and investigation with regard to LPG usage. Currently, the LPG supply chain is not adequately addressed in the existing energy legislation and regulatory provisions for Malawi. An improvement in this regard, which MERA championed, would ensure proper coordination of activities in the sector.

Further, to respond to the growing charcoal/energy problem, the Government of Malawi, led by the Departments of Forestry and Energy, have also been leading a Task Force that is developing a Malawi National Charcoal Strategy (MNCS). The goal of the MNCS is to provide a framework to address the linked problems of increased deforestation and growing demand for household cooking fuel, with defined and prioritized short-term, medium-term, and long-term action. The MNCS has recognized the use of LPG as a viable solution to reduce the demand for charcoal especially in urban households leading to continued loss of forests in Malawi. The selection of the type of fuel during cooking is contingent of several factors. Factors influencing the decision in Malawi are also, availability, affordability, habits, and the usability of the fuel.

The prevailing use of firewood in Malawi is primarily because it is cheap (often free) and widely available (Alexander et al., 2018). In the future wood will remain the primary cooking fuel for rural households. This will lead to further loss of forests which will in-turn impact Malawians in several ways including increased costs of charcoal and firewood due to low supply because of low availability, increased incidences of flooding and erratic rainfall leading to food insecurity (GoM2014). An increase in LPG use could reduce the total amount of wood, coal and kerosene consumed. This is the case in some cities where LPG is available. But households do not tend to fully replace one fuel by another. Instead, they use a mix of fuels, and a specific fuel is chosen according to availability, affordability, and convenience. Pope et al, 2018 indicates fuel stacking (households use of multiple cooking fuel options) provides a sense of energy security, since complete dependence on a single fuel or technology would leave households vulnerable to price variations and unreliable services, especially in the case of LPG in Malawi. As previously stated, the use of subsidies to buy LPG cylinders and LPG would be an effective strategy to promote use of LPG in Malawi. LPG is very expensive and significant sums would have to be invested to develop the markets. The ladder below (Fig. 5) from World Health Organization provides a segmentation of income and households use in reference to the Household Biomass Fuel Use among a Peri-urban Population in Malawi **(**Mortimer, K. (2014**).** LPG government recommended prices in Malawi are presented in Table 4.

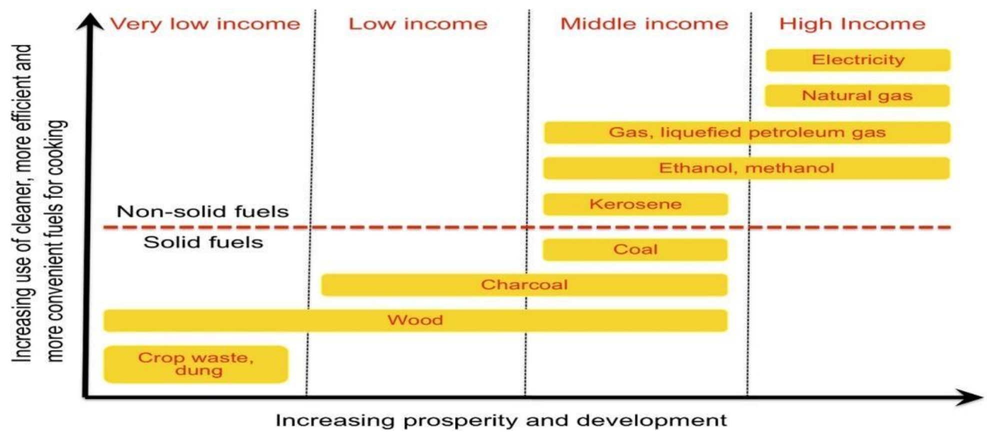


Figure 5 : World Health Organization energy ladder describing the relationship between different types of household fuels and prosperity

Table 3 : LPG Recommended Retail Price by MERA

Current Maximum LPG Retail Price (MWK/Kg)	Recommended Maximum LPG Retail Price (MWK/Kg)	% Change
2,066.27	2,178.70	5.44

Extracted from Malawi Energy Regulatory Authority (MERA, 2020)

i. The maximum current retail price MWK2,066.27 and the maximum recommended LPG retails price is MWK2,178.70

ii. The percentage change is 5.44

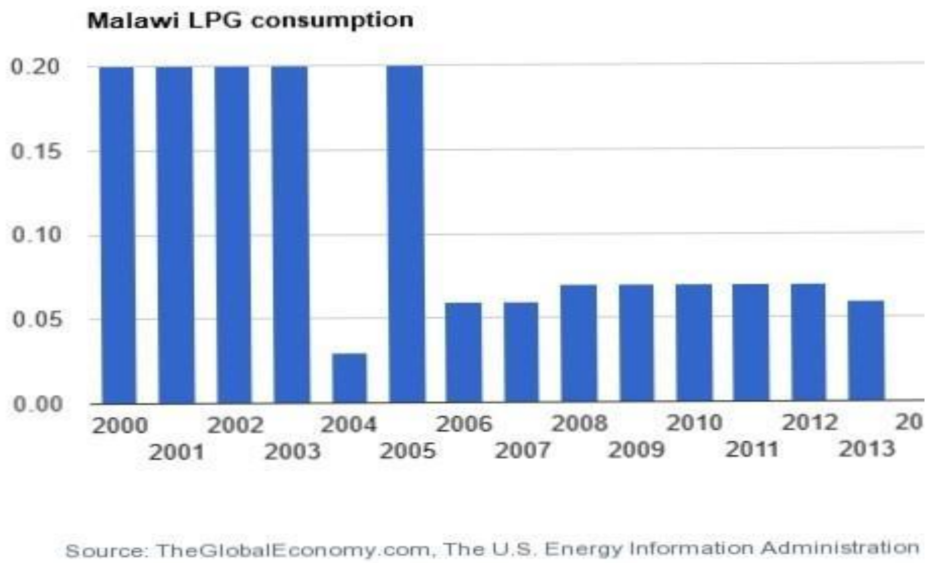


Figure 6 : Malawi Liquefied Petroleum Gas Consumption, (thousand barrels per day)

LPG has multiple linkages with other sectors and sub-sectors of the economy such as forestry, agriculture, transport, education, health, mining, tourism, commerce, manufacturing, and energy. Forests support the development of other important sectors such as agriculture and tourism through provision of water resources and catchments, maintenance of hydrological balance and soil protection (Uhunamure et al., 2019). Further, the forest stabilizes the essential balance of atmospheric gases. The use of natural gas as an alternative to wood fuel for cooking will contribute to the reduction of deforestation rate, thus mitigating climate change (improved rainfall, predictable rainfall seasons, reduced natural catastrophes), resulting in reduction of environmental degradation leading to improved agricultural productivity (Helmy, 2019). The improved agricultural productivity will guarantee food security, stimulate value additions in the food value chain and improve livelihood of rural communities.

2.6 Gender Perspective of LPG

LPG can provide a first modern alternative to traditional cooking fuels e.g. firewood, charcoal and dung) contributing to a better quality of life and importantly liberating women and children from time spent collecting fuel, thus enabling them to pursue education or value added economic activities within the community. While women are the biggest users of LPG for cooking, they are generally not involved in the LPG supply chain. Supply of LPG represents an important employment sector with growth potential directly and indirectly. Engaging women in the LPG supply chain is an effective strategy for gender equality as well as for LPG promotion (Das et al., 2019). Investing in women's economic empowerment sets a direct path towards gender equality, poverty eradication and inclusive economic growth (Microsoft, 2015).

Increasing household use of LPG is one of several pathways to meet the objective of universal access to clean cooking and heating solutions by 2030, one of the three pillars of the UN Sustainable Energy for ALL Initiative under the Sustainable Development Goals, Goal 5. The SDG 5 aims to achieve gender equality and empower all women and girls. The goal includes measures relevant to the energy sector including to end all discrimination against women and girls and recognize and value unpaid care and domestic work through the provision of infrastructure, ensure women's effective participation and equal opportunities, and enhance the use of enabling technologies (Health, 2018). Gender equality matters if energy sector development is to contribute to economic growth and broader development goals. Many of women's traditional income activities are highly fuel intensive, and their viability and costs are affected by energy prices and availability. Fuel is often a significant cost factor in these enterprises and there is therefore a commercial motivation to improve the efficiency of the entire process. Educating the public, especially women cooks, about the costs and benefits of different fuels, is generally considered essential to promote a switch to LPG. Women's fears about LPG safety are not surprising, given the poor regulation and enforcement of LPG supply in many countries, and the unfamiliarity of the technology for many countries (Hossain et al., 2019). New approaches that include training and microcredit, and partnering with formal and informal women's organizations, can help overcome the traditional constraints on women's participation and take advantage of their strengths (Yip et al., 2017).

Recognizing the importance of women in LPG industry, WLPGA set up the Women in LPG Global Network (WINLP) in September 2015, to support and help empower women in the worldwide LPG industry by leadership, coaching, mentoring, and promoting role models. WINLPG aims to increase the number of women in the LPG industry's profile management to 40% and at the board level by 30% by 2030(Kelkar & Nathan, 2021)

2.7 Common barriers to LPG adoption

LPG is a fossil fuel and therefore not renewable (Shah et al., 2018). The quantity needed to satisfy its demand corresponds to about 120 million tons of oil equivalent LPG per year – this equates to 1 % of global commercial energy consumption or 3 % of global oil consumption (Dalaba et al., 2018). Since LPG is a by-product of oil and gas, the amount available is directly tied to the global amount of available oil and gas. The main challenges for broader dissemination of LPG are its limited accessibility and affordability for its users (Leeuwen et al., 2017). Furthermore, a lack of awareness of LPG as well as fear of accidents exists. Consumer education is an essential component in promoting use of LPG in Malawi and other countries in Africa (Ronzi et al., 2019).

Accessibility is often not achieved in the case of LPG. In most countries, access to LPG is limited to urban areas and LPG supply shortages are a frequent occurrence in rural areas (Van Leeuwen et al., 2017). Additionally, due to the low cost of wood-fuel and lack of awareness, increased LPG use is currently not viable for most rural areas in developing countries (Murshed, 2018).

Affordability is still a substantial barrier for many households who want to use LPG (Fan, 2019). Evidence shows that subsidies have benefitted wealthier urban users more than low income users as the former are in a better position to afford the high initial costs associated with LPGV (Gioda, Tonietto, & Ponce, 2018). This is reportedly the case for most countries in which alternative fuels like LPG is/was being subsidized (Blankenship & Urpelainen, 2019). Depending on the amount of subsidies, the retail prices charged in December 2010 varied by a factor of eight, ranging from 0.40 USD per kg in Morocco to 3.26 USD per kg in Turkey (Ali & Rahut, 2019). Research suggests a link between the level of education attained by members of a household and the likelihood of the household to select LPG as their main cooking fuel (Zhao et al., 2019).

Convenience is one of the main reasons why the use of LPG has been growing worldwide (Gioda et al., 2018). LPG heats quickly and provides much greater efficiency than even the most improved biomass stoves (Sola et al., 2019). LPG stoves can also be controlled more precisely to match the user's requirements and can save time for cooking and cleaning the kitchen (Makonese & Ifegbesan, 2018). Additionally, LPG can be transported, stored, and used virtually anywhere.

The development of LPG infrastructure (bottling plants and distribution chains) (Johnson et al., 2019) also remains an important challenge to enhancing LPG market penetration here in Malawi. For instance, Nigeria is theoretically self-sufficient in LPG but lacks necessary distribution systems and purchasing power (Hossain et al., 2019). Regular supply shortages and difficulties in acquiring cylinders are often cited as additional deterrents.

Lack of physical infrastructure in SSA countries is mainly underdeveloped especially the rural areas which adversely affect the distribution of clean cooking fuels such as LPG (Aboubacar, 2018). In rural areas roads are inadequate and in bad condition resulting in high transportation costs making fuels unaffordable to most of the people who are mainly poor (Bruce et al., 2018). Furthermore, rural communities depend more on traditional fuels as compared to those in urban areas resulting in low levels of adoption of alternative clean fuels (Alkhalidi et al., 2019). In urban areas, commercial fuels such as LPG are successful as compared to rural communities because it is simple to distribute fuel in areas of high population density and economies of scale are possible because of high demand in a localized area (Dalaba et al., 2018).

Socio-cultural issues that reinforce the dependence on traditional fuels play an important role in the adoption of clean fuels such as LPG (Gioda, 2019). Most SSA societies are male dominated in terms of making economic decisions in each household. Women who are often responsible for duties associated with household cooking and bear the brunt of its associated costs are not normally involved in the decision making process (Gitau et al., 2019). Therefore, if women were included in the decision-making process for household economics and are well informed of the costs and benefits of different types of fuels, it would be easy for switching to clean fuels. Traditional methods of cooking with firewood are so deeply ingrained in many local cultures that modernization has little appeal, even when the potential savings are recognized (Widijantoro & Windarti, 2019).

Poor flow of information between producers, consumers and intermediary organizations impedes the shift from traditional fuels to clean cooking fuels in SSA (Aboubacar, Deyi, Yac, 2019). Consumers have limited information about alternatives and their benefits to traditional fuels as such they are not able to make informed decisions with regards to the type of fuel they would choose (Mouhoud, 2018). With limited knowledge on the specific patterns of energy use at household levels, it is difficult to determine the market demand and potential for clean cooking programs for specific areas.

Consumers have little information on the consequences of their use of traditional fuel because of low levels of education, specifically health and environmental effects despite the benefits of clean cooking fuel alternatives. As such better public awareness and education would play an important role in people shifting from traditional fuels to clean cooking fuels.

According to Carrión et al. (2018), the three key success factors when switching from traditional fuels and kerosene to LPG are:

i. There must be motivation for change
ii. The value proposition to the consumer must be simple, easy to understand, convincing and affordable
iii. The application of safety and good industry practices is vital to allow the LPG industry to grow in a safe and sustainable manner.

2.8 Key Lessons and Recommendations derived from the Literature Review

The following are the key lessons from the literature review:

i. The demand for LPG worldwide is increasing for its household, industrial and commercial use. In Ghana, LPG demand is increasing in the transport sector due to rising petrol prices.
ii. Governments have played a critical role in all the countries where LPG has been successfully promoted. Government have done this through the following ways:

- Creation of an enabling environment through policy formulation, implementation, and enforcement. Some of the rules and regulation that government can institute to promote LPG include but not limited to:
- Those related to imports and exports of LPG and LPG equipment
- Safety and maintenance regulations,
- Investment incentives for investors in the LPGs Sector,
- LPG Market Liberalization Policy,
- Provision of finance as a director investor. This has been through the Public Private Partnership and through wholly owned government institutions where government has invested amongst others in storage facilities and refineries.
- Provision of subsidies to promote LPG adoption. Subsidies are provided with an aim of making LPG competitive by reducing LPG prices compared to other energy sources and to standardize LPG prices across the country especially transport subsidies. Subsidizes are however required not to be bring about market distortions such as those that discourage private sector investment in the LPG sector.
- Provision of capacity building and certification as is the case in South Africa where LPGASASA certifies LPGs installers.
- Promotion of information sharing through website and even advertising in national newspapers as was the case with the Government of Ghana.

- Provision of tax concessions on the importation LPG products e.g. removal of duty and VAT in order to reduce the price of LPGs compared to charcoal and fuel wood. Taxes can also be imposed on unsustainable energy sources to raise their prices with an aim of making them uncompetitive against LPG.
- Free distribution of LPG equipment as was the case in Indonesia where a total of 44million households were converted to LPG use (with initial free LPG start-up kits including a 3kg LPG cylinder, double burner stove and equipment) in less than four years. The users were responsible for the subsequent costs of refills, which were sold at a subsidized price. The total investment up to 2009 was US$1.7billion approximately US$40 per household across the entire value chain, fuel subsidies excluded (Bruce et al., 2017).

iii. Partnership with key stakeholders is of paramount importance in the promotion of LPG (Dalberg, 2013). Key stakeholders include:

- Financial institutions to provide credit for initial investment in LPG equipment.
- Distributors or transporters who help LPGs to reach the end users even in rural areas.
- Marketing companies for raising awareness about the availability, price and benefits of using LPGs in order to stimulate behaviour change.
- Development partners (donors and NGOs) for supporting government initiative to address loss of forest reserves through implementation of programmes that promotes LPG and other renewable energy sources. For example, UNDP in through its Rural Challenge Programme provided financial resources to promote LPG adoption while in Sudan, Practical Action and other NGOs initiated development projects that played a significant role in promoting LPG through rural participatory methods, capacity building and provision of credit to women development associations. In Mozambique, USAID conducted a market assessment of LPG to inform government policy and promotion of LPGs.

iv. Good flow of information about the environmental, health and economic benefits of LPGs is important in helping consumers switch from biomass or electricity to LPG. Consumer awareness and education will help consumers to appreciate value proposition for using LPG. Information can be provided through the national television and public radio broadcasters, newspapers, websites and posters etc. Some of the information that is required in the LPG market includes:

- Suppliers of LPG,
- LPG price,

- Tax on LPG
- Quantity calculator and
- Safety regulations

v. Consistent LPG supply is important in LPG adoption as the absence of LPG in the market may influence consumers to revert to unsustainable energy sources e.g. charcoal and fuel wood. The supply of LPGs is affected several factors including but not limited to:

- Availability of adequate storage capacity,
- Good road or transport network to facilitate the delivery of LPGs to all parts of the country,
- Availability of LPG equipment and appliances e.g. gas cylinders and stoves. In Ghana, the government established Ghana Cylinder Manufacturing Company (GCMC) to produce more cylinders.
- Technical ability of consumers to use LPG technologies and experts to maintain LPG equipment and appliances.

vi. Household income impacts the adoption of LPG. From the literature review, the adoption of LPG is high in urban areas especially amongst middle to high-income earners as evidenced by the high LPG usage in Khartoum, Maputo, and Accra cities. Semenya & Machete (2019) acknowledges the major drivers of energy fuel use are household income, educational status of breadwinners, family size, and place of residence, fuel affordability and accessibility. Therefore, provision of credit facilities and subsidies are important if the rural poor resourced household are to adopt LPGs.

vii. LPG has a gender dimension, and it is therefore imperative to include or consider women participation in LPG programmes or value chain. As was the case in Sudan where the provision of credit to Women Development Associations (WDA) helped to increase the adoption of LPG. Similar outcomes were noticed in Brazil, Thailand, and Indonesia.

viii. LPG in most countries has been adopted in or around urban areas by the middle class who have access to electricity and not rural areas where there is high dependency on solid fuel energy sources.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Research approach and design

The research focused on assessment of potential uptake of LPG fuel for cooking through the investigation of the phenomenal statistics of both quantitative and qualitative data (Yannis & Nikolaos, 2018). The process of estimating numbers in quantitative research provides the fundamental link between empirical observation and mathematical expression of quantitative relations (Ranjan, 2019). In quantitative research data was typically selected and analyzed in a numerical form.

The qualitative research involves an interpretative, naturalistic approach to the subject matter (Kasangana & Masekameni, 2019). The researcher studied things in their natural setting attempting to make sense or interpret the phenomena of the parameters under research. It further involved collection of a variety of empirical materials eg case studies, personal experience, introspective, life story, interviews, observation, historical, interactions, and visual texts.

Although the above definition implies that for one to conduct a quantitative research data must be in numerical form, it is also possible to collect data that do not naturally appear in quantitative form in a quantitative way (Bößner et al., 2019). This was achieved by designing research instruments aimed specifically at converting that do not naturally exist in quantitative form into quantitative data, which was then analyzed statistically (Uhunamure et al., 2019). As the research objectives and questions indicate the researcher was looking for data that does not exist naturally. However, the research data collection tools- was designed in such a way to collect data in quantitative way as explained under data collection techniques below. The researcher commissioned both quantitative and qualitative methods to determine the market potential of LPG uptake in Malawi. The quantitative evaluation was conducted through household, key informant interviews and institutional surveys in Lilongwe, Blantyre, and Mzuzu Cities. Further the qualitative market research was conducted to determine the supply and demand of LPG in Malawi.

3.2 Sampling and sample size

3.2.1 Sampling techniques

The researcher used purposive sampling technique where households and institutions were chosen. In a similar research purposive sampling method was used and it on households at sub-locational level exclusively using improved stoves and traditional three stone stove, fuel wood only and those using both fuel wood and charcoal (Dalaba et al., 2018). Purposive sampling consisted of subjects selected by the researcher because of their expertise and proximity of the respondents in the area the research was conducted. They were chosen because of their possession of some characteristics the researcher wanted to include. Purposive sample also commonly called a judgmental sample was one that was selected based on the knowledge of a population and the purpose of the research.

The researcher employed a cross-sectional research design employing a two-stage sampling procedure to select urban households for the household questionnaire. As rural households use more than one source of fuel at a time, a multivariate probit econometric approach was used to analyze the determinants of choice of energy sources (Ali & Rahut, 2019) The first stage for the urban household selection was the segregation of the two urban areas by average household income of that area to categorize the areas into high, middle and low income areas. The second stage was the randomized selection of the urban area by average income. The third stage was the actual, randomized selection of households within these areas for each of the categories. This methodology was followed as there is no standard method for sampling households for fuel usage (Gitau et al., 2019). However, there is a positive correlation between per capita fuel consumption and income levels of residents (Hua Liao, 2018). This, therefore, allowed for the classification of the cities into locations depending on the income levels as high income, medium income, and low income.

The Slovin's formula was used in sample size determination. It was used to determine the sample size denoted as (n) given the population size denoted as (N) and a margin of error denoted as (e) (Ansar et al., 2017). The Slovin's formula is a reliable random sampling technique used to calculate samplesize, it is computed as

$n = N / (1+Ne^2)$ ………. (1)

Where

n = Sample size

N = Total population

e = error margin / margin of error.

The formula was used to determine the number of respondents in all main cities ie Lilongwe, Blantyre, Mzuzu. The 2018 National Population and housing census reported that for instance Lilongwe city has **230,265** total households. The population density of Lilongwe City was reported to be **2,453 per km^2**. The researcher used the total number of households in the city to determine the sample size per category of the areas segregated according to their income levels. A stratified random sampling was employed to find a representative sample in households' categories. In Lilongwe the categories were as follows (Table 4):

Table 4 : High, Low and Medium areas in Lilongwe

High Income	Middle Income	Low Income
Area 43	Area 49	Chisapo
Area 47	Area 50	Area 23
Area 14	Area 18A	Biwi
Area 15	Area 30	Mchesi
Area 6	Falls	Area 24
Area 9	Area 25	Area 22

Data in Lilongwe was collected in Areas 9, 10, 23, 47, and 49

3.2.2. Stratification

In Lilongwe city sample size was calculated through the formula: $N / (1+Ne^2)$. Lilongwe city has 230,265 households (NSO., 2018). The sample size was calculated and found to be 133

Table 5 : Sample Size Calculation for Lilongwe

Category	Total Population	Sample Size
Households	N	$N / (1+Ne^2)$.=230,265/1+230,265$(e)^2$=400

$$\mathbf{N=400=\sum (N_1=N_2=N_3 \sim 133)}$$

Table 6 : Description of N for High, Low and Middle Income areas

Sub Category	Sub Samples
Low Income	N_1
Middle Income	N_2
High Income	N_3
TOTAL	**~400**

Blantyre city has a 191,676 households (NSO.,2018). The sample size using the formula $N / (1+Ne^2)$ was found to be 400 for the three neighbor hoods where data was collected.

Table 7 : Sample size calculation for Blantyre

CATEGORY	Total Population	Sample Size
Households	N	N / (1+Ne^2).= 191,676/1+191,676 (e)^2~400

Blantyre City was established in 1870s by the Scottish missionaries, it remains the commercial city of Malawi and has 191,676 households in the urban area (National Statistical Office Malawi, 2018). The researcher used the number of households in the city of Lilongwe to determine the sample size. In Blantyre data was collected in BCA Hills, Namiwawa, New Naperi, Chilomoni and Chilimba as presented in Table 8:

Table 8 : High, Low and Medium areas in Blantyre

High Income	**Middle Income**	**Low Income**
Mount Pleasant-Chigumula	Chilomoni Fargo	Ndilande
Namiwawa	Chinyonga	Mbayani
BCA Hills	Naperi	Machinjiri
New Naperi	Chitawira	Chilimba
Nyambadwe	Nancholi	Lunzu
Chigumula	Manja	Chichiri

Table 9 : Sample Size Calculation formula for Mzuzu

Category	Total Population	Sample Size
Households	N	N / (1+Ne^2).= 49,564 /1+49,564 (e)^2~400

Mzuzu is the third largest city stituated in the northen part of Malawi, it has has 49,564 households (NSO, 2018). The researcher used the number of households in the city to determine the sample size through the Slovins formula. The categories for random sampling in Mzuzu were as Table 10; data was collected in Chimaliro, Old Katoto, SOS/Hilltop and Masasa areas.

Table 10 : High, Low and Middle income areas in Mzuzu

High Income	**Middle Income**	**Low Income**
New Katoto	Chibavi	Mchengautuba
Chimarilo	Luwinga	Chiputula

SOS/Hill top	Chibanja	Zolozolo
	Old Katoto	Masasa
		Chasefu

3.3 Data Collection and main research areas

The maps below indicate researcher areas where data was collected in main cities of Blantyre (Fig. 9), Lilongwe (Fig. 8) and Mzuzu (Fig. 7).

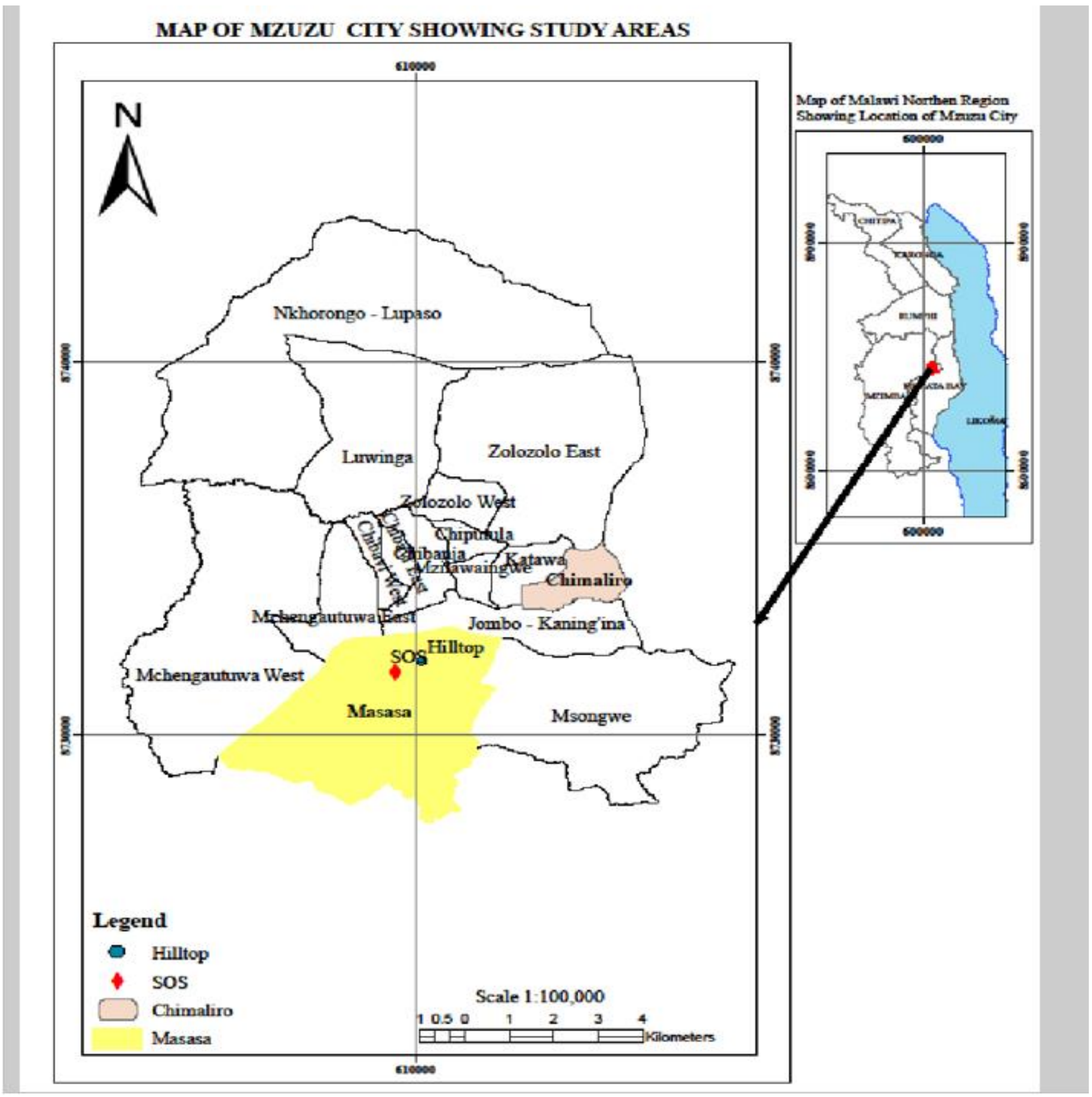


Figure 7: Map of Mzuzu showing some study areas highlighted in colour

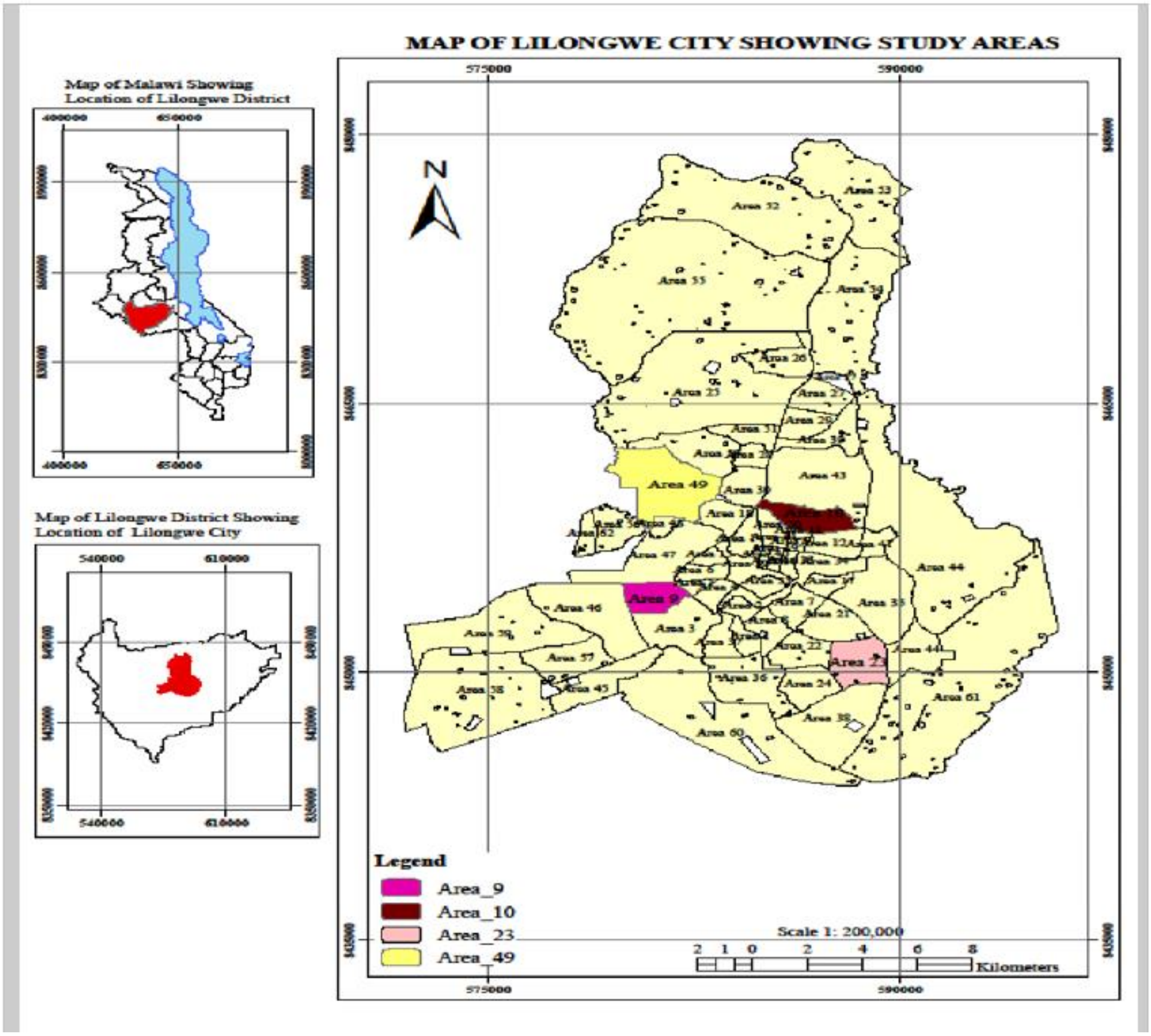


Figure 8 : Map of Lilongwe study areas highlighted in pink, purple, yellow and marloon as shown on the legend

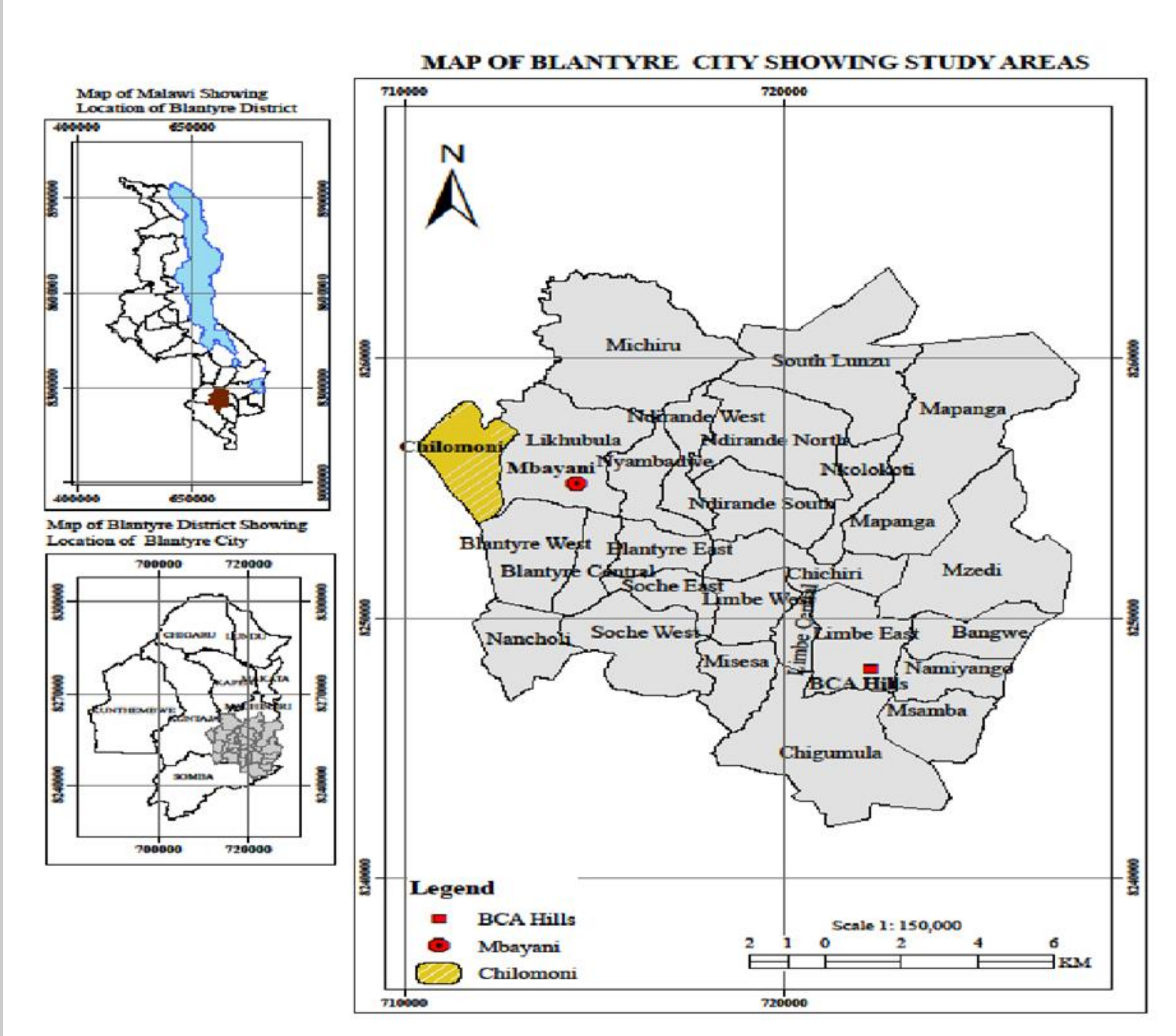


Figure 9: Map of Blantyre study areas highlighted in red and yellow as shown on the legend

The researcher engaged 9 research assistants who collected data in Mzuzu, Lilongwe, Blantyre City; a total of 1500 households were interviewed. After all paper-based surveys collected, the data was entered into excel and then transposed to IBM Statistical Package for social scientists (SPSS) for analysis.

Data collection took a period of two months as opposed to the initial arrangement highlighted in the proposal where one month was scheduled for the data collection exercise. This ensured that the respondents are given enough time to reflect on the issues highlighted in the questionnaire and it provided ample time for the interviews hence improved the quality of data collected. The researcher used different data collection techniques where the data gathered from the different sources was triangulated for validity. Several techniques were used to collect the data which was dependent on the availability of time especially the key informant interviews and financial resources.

3.3.1 Objective 1: To assess willingness to pay and private sector investment across the LPG value chain in Malawi

The LPG market assessment was conducted in nine districts: Mzimba, Karonga and Mzuzu City in the Northern Region; Lilongwe, Kasungu and Salima in the Central Region; and Blantyre, Zomba and Mangochi in the Southern Region. These districts were targeted to collect a representative, regional sample as well as to increase the probability of finding both users and non-users of LPG. Considering time and financial constraints, the sample size for this research was limited to 300 households. To achieve balance, it was decided that half of the overall sample must be LPG households (households which own and use LPG gas) and the other half would be non-LPG households (households who do not have or use LPG gas). Geographically, it was decided that a minimum of 100 households would be interviewed from each of the three regions, 50 of which were LPG households and the other 50 non-LPG households. An example of the Household Survey Questionnaire on LPG Market Assessment is included in the Appendix B.

Furthermore, to achieve this objective the institutional questionnaire was designed in which the researcher interviewed institutions which are currently using LPG on large scale, assessed their willingness to pay and those who have potential to use LPG; such institutions were schools, colleges, hospitals etc.

Considering the low adoption rates of LPG across Malawi, the institutional sample was decided to be a minimum of 45 interviews. Here, it was decided that nearly all institutions to be covered should be those that are using LPG as one of the main institutional cooking fuels. To ensure spatial balance, a minimum of 15 interviews from each of the three regions was the target.

This target was surpassed such that 82 institutions inform of schools, lodges, hospitals, industries, or commercial users of LPG were interviewed. To ensure that all actors surveyed were actual users of LPG, purposive sampling was used for the institutional surveys while simple random selection was used to select institutions, industries, and commercial users of LPG. Table 12 below details the type of institutions surveyed.

Table 11: **Number and types of institutions interviewed**

Institutions	Number Interviewed
Lodges	32
Hotels	7
Schools	12
Hospitals	5
Restaurants	21
Other	5
Total Sample	**82**

The researcher was able to gather data and understand the LPG market potential in respect to supply and demand as the key informant interviews were also conducted. It involved interviews with LPG suppliers (Afrox, Delta Gas, and Gas Man), Malawi Energy Regulatory Authority (MERA), and the Department of Energy Affairs (DoEA) were all interviewed. An in-depth interview guide was utilized during the key informant interviews, and it is included in the appendix for reference. The data collected provided gaps and strengths for LPG market in Malawi. The policy makers and the sector players provided information for the researcher to deduce the current environment and bottlenecks that hinder LPG uptake in Malawi and suggestions for a wider uptake.

3.3.2 Objective 2: To assess household's preferences on available cooking fuel alternatives (electricity, charcoal, firewood,) comparative to LPG

To achieve this objective household surveys were conducted in urban areas of Lilongwe, Blantyre and Mzuzu where charcoal is highly consumed. These households were selected through purposive classified sampling, categorizing households as low, middle, and high income. The questionnaire was designed to capture the households' expenditure on the current energy sources used, their willingness to pay, challenges encountered when using LPG, perceptions and areas that needs to be improved in LPG distribution channel. It also assessed the income of households spent on alternative energy sources like charcoal, electricity, and firewood. This helped in cross tabulation to understand the relationship of various variables especially deducing what triggers households to use a particular source of cooking fuel as opposed to others.

3.3.3. Objective 3*: To deduce the efficiency of LPG as compared to other available cooking fuel alternatives in Malawi*

To achieve this objective, the efficiencies of charcoal, electricity, firewood, and LPG the researcher conducted controlled tests of efficiency of cooking fuels and technologies in a laboratory setting from the laboratories of Malawi Bureau of Standards (MBS) and Malawi University of Science and Technology (MUST). The water boiling test (WBT) was used where stoves were operated on firewood, charcoal, LPG and electricity. The WBTs were conducted following the protocol stipulated in The Global Alliance for Clean Cookstoves WBT (The Global Alliance for Clean Cookstoves, 2014). In this research, the WBT utilizes medium sized aluminium pots with an initial water loading of 1.5 kg. A complete WBT was done in 3 phases vis-à-vis high power cold start, high power hot start, low power simmering testing. After these measurements were recorded, an average of these were calculated to determine the final WBT score. A reference guide for the technology appliances tested and a template data collection sheet for the WBT phases can be found in the appendix D.

For the first two phases of the WBT, the time taken to raise the initial water temperature to boiling point was recorded, at simmering phase measurements were recorded for 45 minutes. Additionally, the amount of fuel consumed, and the amount of water lost through evaporation in each phase were also recorded. The firewood used for the WBT test on firewood stoves was indigenous masuku a mtchile firewood. This firewood was selected for the research as it is found throughout Malawi and is a common and preferred firewood by both Malawian urban and rural firewood users. Charcoal stove WBT were done using two types of charcoal: local charcoal (LC) and Kawandama Hills Plantation Charcoal (KC). These two charcoal varieties were used to represent the common, unsustainable, illegal charcoal used in Malawi (the LC) and the less-common, sustainable, legal charcoal available in Malawi (the KC). Finally, the LPG WBT was done with Afrox LPG while ESCOM grid electricity was used for the electricity WBT. For each cooking fuel, a WBT was conducted from which appropriate variables were measured and performance metrics were calculated.

For each fuel, three full WBTs were conducted, and arithmetic mean variables were used in the calculation of three performance metrics, namely: temperature-corrected for time to boil (t_{bT}); thermal efficiency (η_T); and turndown ratio (TDR). The t_{bT} variable measured the time the fuel or applicance took to boil water in the first and second phases. This was corrected to reflect a temperature rise of 75 °C from start to boil. The η_T variable measured the fraction of heat produced by the fuel that made it directly to the pot and water. Finally, the TDR variable indicated how much the operator adjusted the heat between high power and low power phases. The mathematical expressions used to calculate t_{bT}, $\eta_{T,}$ and TDR are correspondingly given in equation 2 to 3. The definitions of the notations used in these equations are given in the Table of Notations.

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

$$\eta_T = \frac{(\eta_T)_c + (\eta_T)_h}{2}$$

(3)

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

(4)

The laboratory testing also included controlled cooking tests (CCT). CCTs were conducted to generate data on the cost of energy and thermal efficiency of each fuel and cooking appliance for cooking nsima. Considering nsima is the standard meal in Malawi, this was the food used in the CCT. The CCT data was also used to validate the WBT results.

The cooking of nsima was controlled by fixing the amounts of ingredients (1kg water and 0.3kg maize flour) as well as following an identical cooking procedure. The amounts of maize flour and water were chosen to be representative of an average nsima meal for three people. The cooking steps followed were:

a) Heat 1kg of water to temperature around 45 °C
b) Add maize flower to make a porridge
c) Wait until the water in porridge starts boiling and let it boil for 5 minutes
d) Add the remaining maize flour (all 0.3kg) while stirring the porridge until the nsima is cooked

A CCT was done once for each fuel (firewood, LC, KC, LPG, and electricity) and for each cooking appliance (Three-stone, Chitetezo Mbaula, Envirofit, LPG stove, and electric hotplate). For each cooking task, the amount of fuel utilized was also measured. The cost of energy (written in Malawian Kwacha (MWK)) used per WBT or cost of energy used per 1kg of nsima (MWK/kg

Nsima) were used to measure the normalized cost of using each fuel. Equation 4 and 5 were used to calculate the cost of energy (MWK/WBT) and the cost of energy to cook nsima (MWK/kg Nsima).

$$\frac{MWK}{WBT} = C_f \times Q_f \times \underline{EHV} \quad (5)$$

$$\frac{MWK}{kg\ Nsima} = \frac{C_f \times Q_f \times \underline{EHV}}{Mass\ of\ nsima\ cooked} \quad (6)$$

All temperatures required in the computations of equations 2-6 were measured by a digital thermometer equipped with k-type thermocouple for temperature probing. The thermometer was accurate to 0.1^{o}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. For bigger quantities, a 100kg capacity scale with 0.05kg accuracy was used. The moisture contents of the firewood and charcoal used in the tests were determined through pre-weighing of 100g samples, oven drying, and post weighing of the samples. The samples for firewood, LC and KC were made in triplicates. Further, the heating value of firewood (18,414kJ/kg), local charcoal (29,800 kJ/kg), KC (29,500 kJ/kg), and LPG (44,700 kJ/kg) were obtained from The Global Alliance for Clean Cooks toves (2014). Further, the unit cost of each fuel was calculated based on the current market price.

A T-Test at 95% confidence was used to check significant difference of the mean tbT, η_T, MWK/WBT and TDR for the Chitetezo Mbaula and the three-stone fire firewood stoves from which a better performing stove was selected for further comparison with charcoal burning, LPG, and electric stoves. Similarly, T-Tests at 95% confidence were used to check significant differences (in terms of t_{bT}, η_T, MWK/WBT and TDR) between the Jiko and Envirofit charcoal burning stoves as well as between the Envirofit stove when burning LC and KC. Of the two, the better, most cost-effective charcoal burning cookstove was selected for further comparison with LPG, firewood, and electric cookstoves. The Envirofit stove was compared to other stoves using both the KC and the LC. 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 a one factor Analysis of Variance (ANOVA).

3.3.4 Desk Review

To collect data for all objectives the researcher also reviewed already existing data from previous research reports on LPGs done in Malawi and other countries, online resources, and other reports available in and outside the country mainly in the Sub Saharan African Regions were also reviewed.

3.3.5 Questionnaire/Face to face In-depth interviews.

This involved the collection of primary data through use of a predesigned and tested questionnaire to gather mainly quantitative data as much as possible. This data collection technique involved collection of large amounts of data from larger sample size of the population for objective 1 and objective 2. Both purposive and random sampling methods of the population were done to identify interviewees or respondents for the face-to-face interviews.

3.3.6 Key Informant Interviews (KII)

The researcher interviewed key players with knowledge of LPG to collect data for objective 2. The researcher then developed a checklist to collect information from the KII clients.

3.4 Data analysis

The data collected was analyzed using Microsoft excel and IBM Statistical Packages for Social Scientists (SPSS) presented in graphs using SPSS, matrices, charts, or networks as discussed above, SPSS was used to analyze such data.

The data collected under objective 3 was both qualitative and qualitative in nature and the researcher transcribed, and then generated categories and main themes. The themes developed from the data formed the general context of the feasibility of LPG market potential. The researcher also used this information to develop recommendations for massive scale up of LPG in Malawi. The laboratory tests further supported the results on comparative costs and efficiencies of fuels under research.

3.5 Validity and Reliability

Van Hoeven et al. (2017) defined data validity as whether values from the research findings make sense; data is considered valid if the data represent what they claim to represent. The validation approach started with selecting validity concepts from previous literature and applying these to the data. First, existing frameworks were identified in the literature, from which then relevant concepts were selected, and finally, the concepts were operationalized in terms of the final application.

Furthermore, Noble & Smith (2015) depicts the reliability of research findings depends on the researchers to make judgments about the ‘soundness’ of the research in relation to the application and appropriateness of the methods undertaken. Validity and reliability of the findings of the research presented in this research were ensured through;

i) The collection of data through structured questionnaires, key informants as well as interactive interviews. This ensured that high quality data was collected as methodological errors were minimized through triangulating data collection methods.
ii) The collection of data from cross data sources minimized source data errors and hence improved the quality of the data collected.
iii) The collection of both primary and secondary data ensured that validity is maximized through minimized source data errors.
iv) The researcher used statistical tools like SPSS to analyze data and hence results were derived and enhanced the reliability of the results.

3.5.1 Quality Control

The researcher recognizes the importance of collecting high quality data which is critical to achieving the research objectives. The researcher therefore did the following:

a) recruited well experienced enumerators who were oriented on the objectives of the LPG Market Assessment
b) trained enumerators on data collection techniques;
c) the researcher closely supervised the data collection process;
d) allocated adequate financial resources and transported to ensure seamless data collection process; and
e) developed document control or reference procedures for tracking reports from each enumerator and questionnaires

3.6 Research Ethics

Research ethics is a very critical component to be considered whenever the researcher is doing an investigation.) Reed-berendt et al. (2022)defined research ethics from the premise "Do unto others as you would have them do unto you". Therefore, research ethics is a code of professional conduct like the Hippocratic Oath ("First of all, do no harm"). This is regarded as the most common way of defining "ethics": norms for conduct that distinguish between acceptable and unacceptable behavior.

In line with Reed-berendit argument, the following were considered;

i) The researcher proactively approached different departments in the energy sector related to the research to access the relevant data for the purposes of carrying out the research.

ii) The respondents were briefed of the objectives of the research and were not forced to participate in it. The respondents participated in the research voluntarily and were given consent to participate in it.

iii) Participants were assured confidentiality. Further, in all the writing of the thesis and the published work, pseudonyms were used to protect the identities of participants.

iv) Information that would lead to clues to the real names of the participants were kept confidential and were not discussed outside the research.

3.7 Research Limitations

The significant limitations of the research are:

i. LPG Gas suppliers viewed the researcher as competitor who would like to venture into LPG distribution as such they could not allow to be interviewed or hide some of the information, opportunities, and barriers of LPG in their responses, hence distorting the results. To counter this limitation, the researcher introduced the research to the respondents clearly indicating why it is being carried out and the benefits which could be derived from the results of the research.

ii. The research would be difficult to generalize to the whole Malawi because the researcher targeted main cities which are the major consumers of charcoal leaving out districts. However, the sample selected from cross different groups and three major cities were interviewed suggesting that the results could be generalized to an extent

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the empirical results of the analysis of the data collected during the research using the methodology discussed in chapter three section 3.3 First, household fuel survey results are presented starting with the general descriptive socio-demographic statistics of the households under research. Second, results on the composition, sources of cooking fuels and market uptake potential are presented, followed by 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 which were conducted at MBS and MUST.

4.1 Objective 1: To assess the willingness to pay and private sector investment across the LPG value chain in Malawi

4.1.1. Household Demand for LPG

The household questionnaire revealed high levels of LPG awareness as 74% of households confirmed they were aware of LPG as an alternative cooking fuel. Of these LPG-aware households, the majority knew of LPG through friends or family. Despite this high level of awareness, the level of LPG use was low in these sampled households. The most frequently reported reason that the surveyed households were not using LPG is that they felt LPG was unsafe to use. The second most frequent reason had to do with the households' perception that LPG is expensive. The third most reported barrier to using LPG among non-users was a lack of knowledge of where to buy or access LPG equipment. The research further established that due to the high availability of charcoal and firewood households were not forced to seek alternative cooking fuels such as LPG.

The LPG-users surveyed reported benefits of efficiency (39%); reliability (37%) and cleanliness (27%). Respondents referred to ESCOM's persistent electricity cuts as the reason they find LPG to be a reliable cooking fuel. However, the respondents reported the main challenge associated with LPG was the distance required to travel to refill LPG cylinders. A year after the implementation of the programme, 89% of the surveyed households reported that they still used LPG for cooking, albeit not everyday

Both LPG users and non-users were surveyed as to their willingness to pay for LPG. The research used the direct elicitation approach via an iterative bidding game to establish the amount respondents were willing to pay for LPG, including a gas cylinder and an LPG cooking appliance per month. The data established that sampled households are willing to pay MWK 62,322 for LPG per month. In Table 14 below, a profile of WTP by gender, education and income level of household head is presented.

Table 12: Willingness to Pay for LPG

Characteristics		**Willingness to Pay (MWK)**
Gender	Male headed	65,197
	Female headed	61,957
Education	Primary	43,556
	Secondary	51,484
	Tertiary	67,770
Income	50,000 – 200,000 MWK	39,311
	201,000 – 500,000 MWK	61,381
	501,000 – 800,000 MWK	66,872
	800,000 – 1,000,000 MWK	81,828
	1,000,000 MWK and above	79,958

The assessment also found that, among LPG users, the initial decision to start using LPG as a cooking fuel was made by men (80%). Unlike with firewood and charcoal, it was observed that men participate in the purchase and refilling of LPG gas cylinders while women do most of the cooking. This tells us that efforts to promote LPG should be targeted at men as well as women.

The results of the key informant interviews, institutional and household surveys, established a high potential for LPG market development and growth especially in urban areas. Through pay-as-you-go schemes and by making smaller LPG cylinders (1kg or 2kg) available, the demand for LPG could be stimulated as consumers overcome the barriers of affordability and portability to switch to this cooking fuel. Furthermore, the market analysis revealed potential for market growth if customers could access LPG on credit. Key informant interviews with LPG suppliers highlighted LPG suppliers that are already offering credit options through employer guarantee schemes. LPG suppliers also highlighted Government of Malawi subsidies as an opportunity to also scale-up LPG adoption and distribution. In this research, countries in the region with high LPG uptake had offered LPG-related subsidies to consumers that established this fuel choice.

The Figure 10 below shows the correlation between the household income and willingness to pay, the research found households that had higher income levels had more ability to adopt LPG as compared to those that had little disposable income.

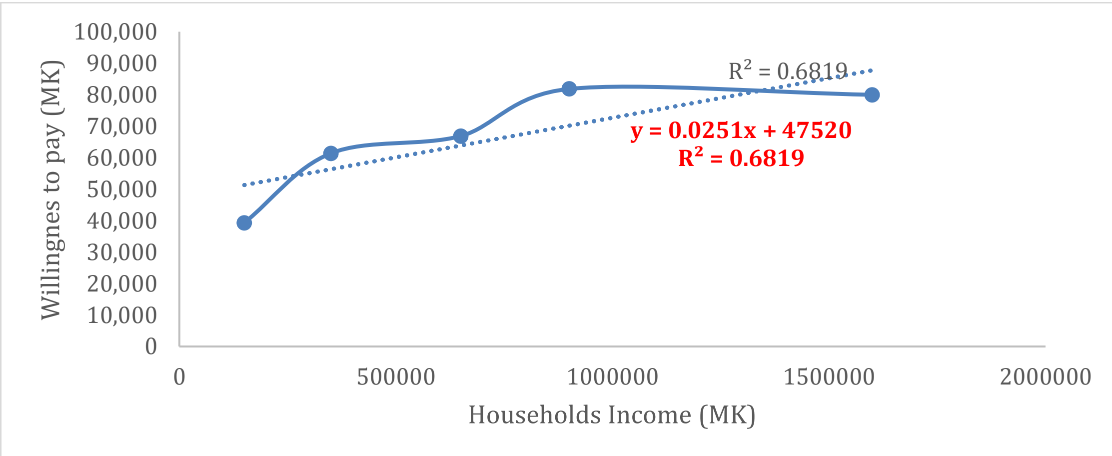


Figure 10: Correlation between household income and willingness to pay

4.1.2 Institutional demand for LPG

The institutional surveys 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 the back-up fuel for 100% of the institutions surveyed. This can be understood through Figure 11 which shows that LPG is perceived as an affordable fuel option by 26.3% institutions.

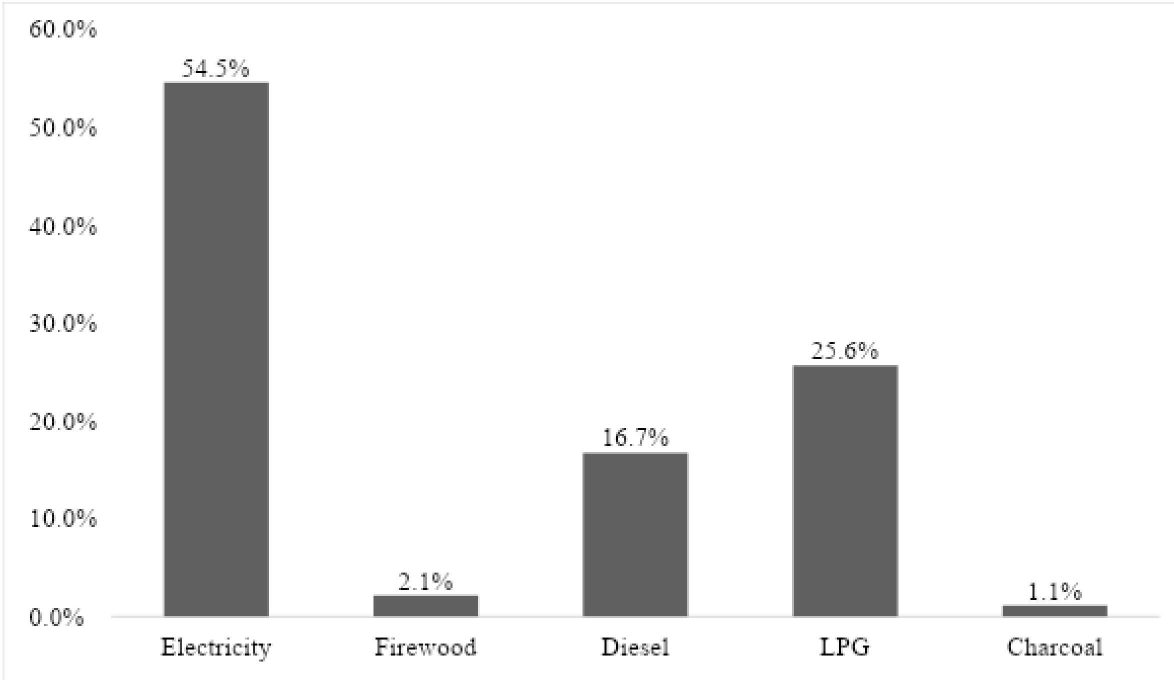


Figure 11 : Institutional cooking fuel preference

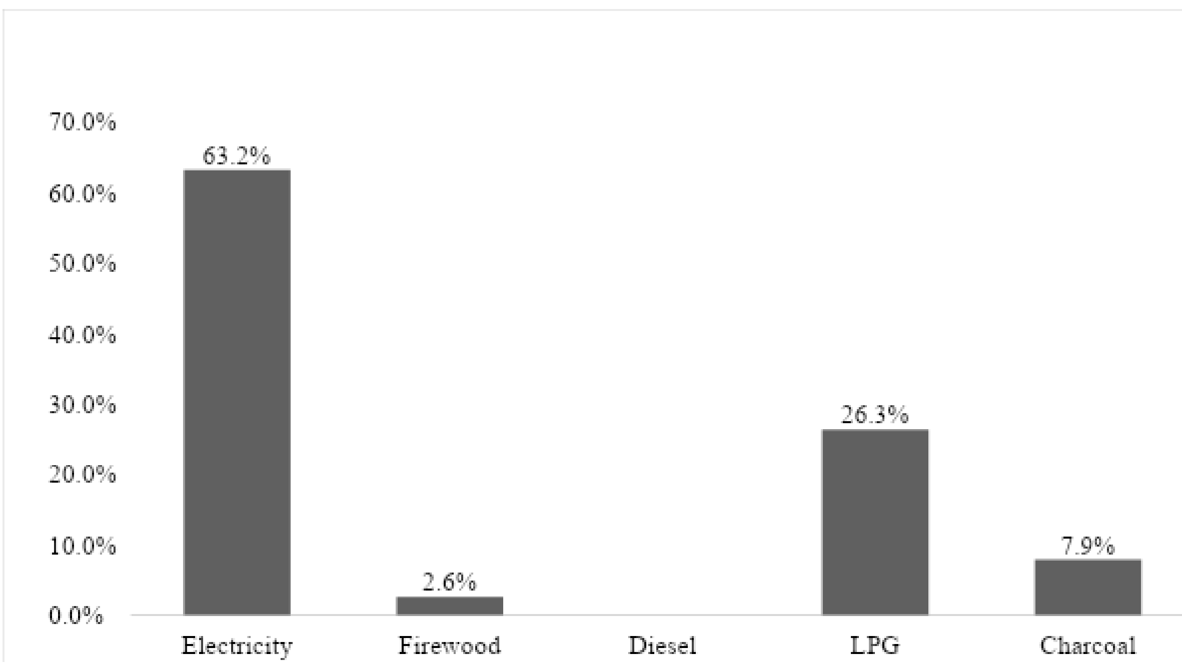


Figure 12 : Cooking Fuel Affordability by Institutions

4.1.3 Supply of LPG

The research found that the distribution network for LPG in Malawi is not widely developed. Except for Afrox Malawi Limited, this has a network of distributors that includes Gasman in Blantyre, Chigodi in Lilongwe, Gas and Gadgets in Zomba, and Mzuzu Panel Beaters in the Northern Region.

Key informant interviews with leading LPG suppliers such as Delta Gas and Industrial Oxygen Company Ltd. found that suppliers face challenges importing gas into the country as processes and logistical issues can require a month for gas to be delivered to Malawi from Zambia or South Africa. In addition, importers are required to pre-finance LPG imports and the Government of Malawi charges 16.5% VAT. These costs make LPG retail prices higher than the average regional prices. On a positive note, all suppliers interviewed indicated they offer training in installation, repair, and maintenance to LPG customers.

The results of the research with suppliers and or importers established that there is potential for LPG market development and growth especially in urban areas. This is especially true as frequent power outages and rising electricity tariffs continue to stimulate demand for LPG. Available data shows that LPG import volumes have steadily increased since 2013. Figure 13 below show MERA’s data on LPG imports by year.

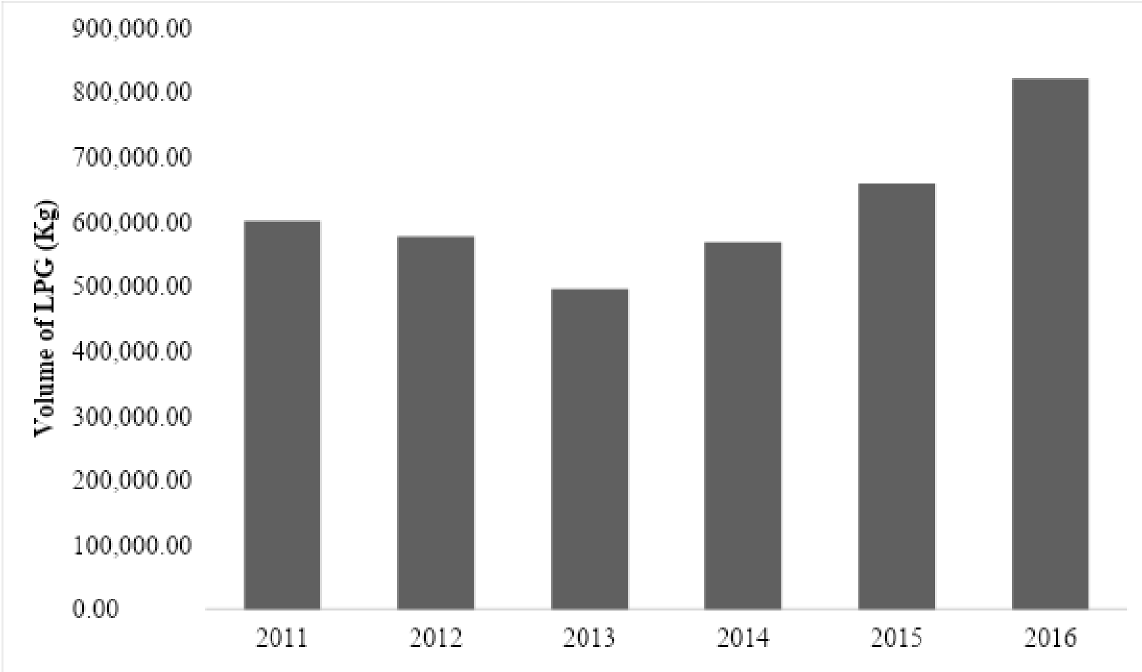


Figure 13 : Volumes of LPG Imports in Kilograms by Year (MERA)

4.1.4 Regulatory Framework for LPG Market in Malawi

The research targeted the Ministry of Natural Resources, Energy and Mining (MNREM); the Malawi Energy Regulatory Authority (MERA); The Malawi Bureau of Standard (MBS); The Ministry of Labor's Department of Occupational Safety and Health; and the Ministry of Finance, Economic Planning and Development. It was noted that the MNREM has recently completed the review of the National Energy Policy where LPG has been earmarked as a viable alternative energy source. Ronzi et al. (2019) echoed the need for government planning to spearhead uptake of LPG in the country. The new Malawi energy policy aims to reduce reliance on firewood as the main energy source to 30% by 2030. To draw special attention and garner support from key value chain actors, the new National Energy Policy has separately categorized LPG, natural gas and biogas from the other energy sources unlike in the previous policy. Building on the positive impacts of the fuels at household level could be a step stone to wider uptake of alternative cooking fuels in the country(Gould et al., 2020).

It was noted that the Government of Malawi established MERA to regulate, monitor and issue licenses to energy sector businesses. MERA ensures that there is compliance with the Liquids, Fuel and Gas Production and Supply Regulations and Energy Laws. MERA in 2018 developed the LPG framework which will guide and provide conducive environment for LPG adoption in Malawi.

MERA also ensures that there is fairness in pricing of energy products and or services. MERA achieves this by setting the maximum consumer prices of energy products. The trend of this pricing can be seen in the Figure 4 below.

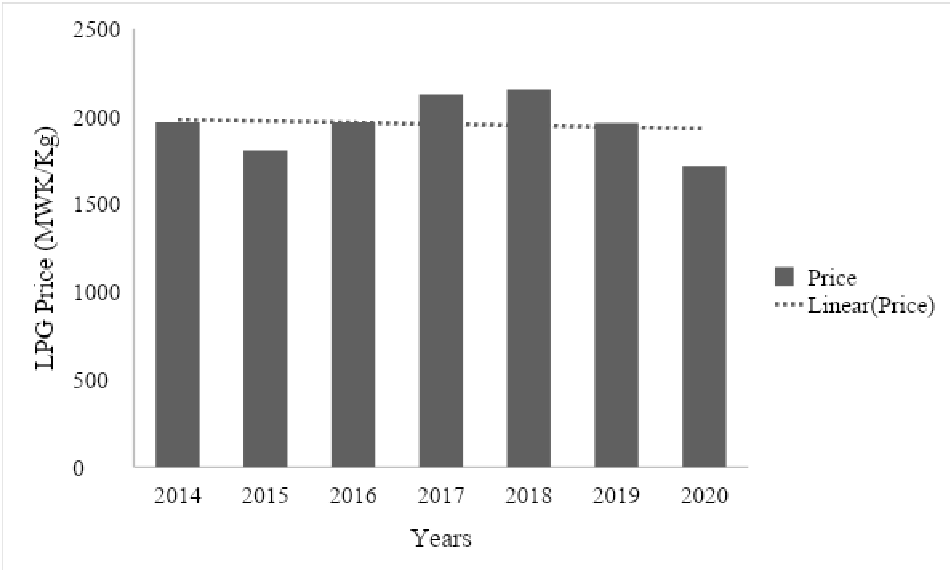


Figure 14 : LPG Price Trends by Month (MERA)

From the Figure 21, it can be observed that prices for LPG have remained relatively stable over the last couple of years and mostly pricing stability should help to stimulate LPG adoption (Dalaba et al., 2018). Though MBS has developed a number of standards relating to LPG production, distribution, storage, installation, consumption and disposal, none of the suppliers or distributors interviewed mentioned anything about complying with MBS standards. However, all suppliers referred to international LPG standards. This could indicate a lack of monitoring or enforcement in the LPG sector.

4.1.5 LPG has potential to place charcoal for cooking in urban areas

The researcher noted the increase in demand for cooking fuel is due primarily to the population growth and continued dependency on wood fuels as the primarily energy source for cooking. National demand for fuelwood, charcoal, and small construction material is projected to increase from 11.2 Mt DM in 2016 to 13.3 Mt DM in 2021 (Drigo, 2019). Most relevant are the changes taking place in urban areas. The rapid increase of charcoal demand (+10% annually) is only partially compensated by the reduction of fuelwood demand (-5% annually) (ibid). Furthermore, alternative fuel sources are perceived by most people to be expensive, the following table highlights the costs of alternative fuels:

Table 13 : Fuel Cost Estimates

Energy prices in Malawi Kwacha on 08 March 2020	
Petrol	930.00/Litre
Diesel	887.00/Litre
Paraffin	693.60/Litre
Liquid Petroleum Gas	1,744.75/Kg
Electricity	88.02/KWh

Source: Malawi Energy Regulatory Authority (2020)

Furthermore, the pricing trends of electricity charcoal and LPG since 2015 are highlighted in table 22 below. The trends show that LPG has been relatively flat on a per KG cost since 2015, residential electricity costs have been steadily increasing with step up in pricing as determined by MERA, and charcoal pricing has shown a continual increase in cost per a 50 kg grain bag, which is estimated to weigh approximately 13 kgs when filled with charcoal. This trend, if it continues, demonstrates the dynamic nature of the cooking fuel costs, and shows the informal charcoal pricing continually increases, this is likely the result of increasing demand for charcoal as urban populations grow, while the supply decreases due to continued deforestation in Malawi. The price trends show LPG as the most promising and impactful alternative fuel to cooking in Malawi (Fig. 15)

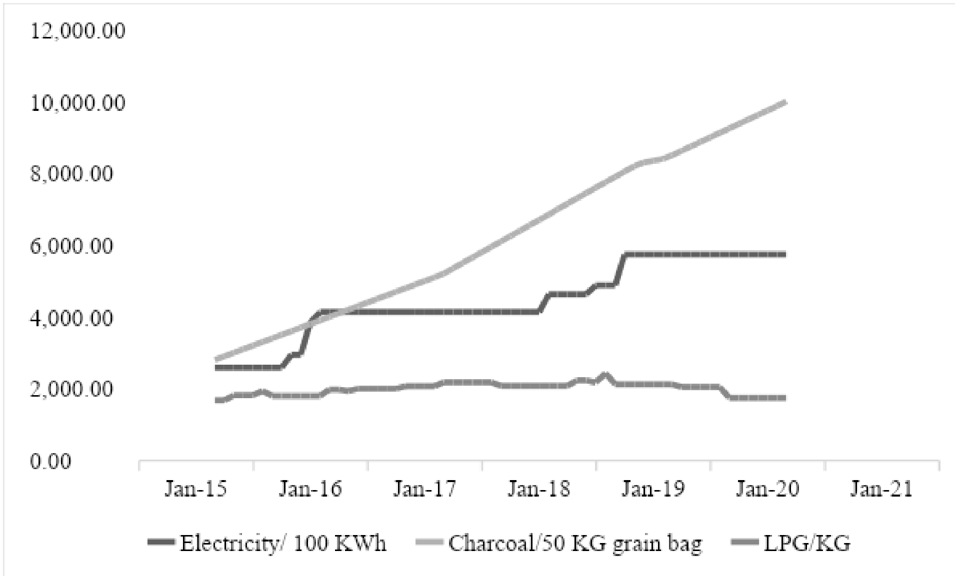


Figure 15 : Electricity, Charcoal & LPG Pricing Trends

Source: ESCOM & Malawi Energy Regulatory Authority (2020)

4.2 To assess household's preferences on available cooking fuel alternatives (electricity, charcoal, firewood,) comparative to LPG

Before discussing the empirical results, the researcher will briefly discuss features that characterize the data. Several 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 research are the number of people per households; average income level per household; education levels affordability, and who does most of the cooking at in the household.

In the research as shown in Table 14 below, 29% of those interviewed were male while 71% were female. Six % (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 research largely dealt with low income households who were mostly headed by females. Using the NSO poverty line of MK37, 002 the per capita income average household included in the research was poor. The statistics described above are useful for setting a general context of the sample used in the research.

Table 14 : Demographic characteristics

Descriptive Statistics				
General Sampled Population	**High Income Urban Areas**	**Middle Income Urban Areas**	**Low Income Urban Areas**	**Rural Areas Impact Areas)**
29%	23%	34%	21%	30%
71%	77%	66%	79%	70%
38%	40%	36%	35%	38%
6%	2%	0%	0%	7%
55%	4%	0%	24%	63%
24%	15%	32%	57%	22%
15%	79%	68%	19%	7%

4.2.2 Household Surveys

a) Average Household Expenditure of Cooking Fuels

Figure 16 below shows that urban households spend on average MWK 25,942 per month on cooking fuel while rural households spend only MWK 3,211 per month on cooking fuel, the figure below shows the average household energy expenditure by area. The urban households in low density areas spend more on energy due to their high income status (Xiaowei Ma.,2020). This was also backed by Uhunamure et al.,(2019) who lamented income status as a main reason for high energy expenses in urban households. 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 the surrounding forests.

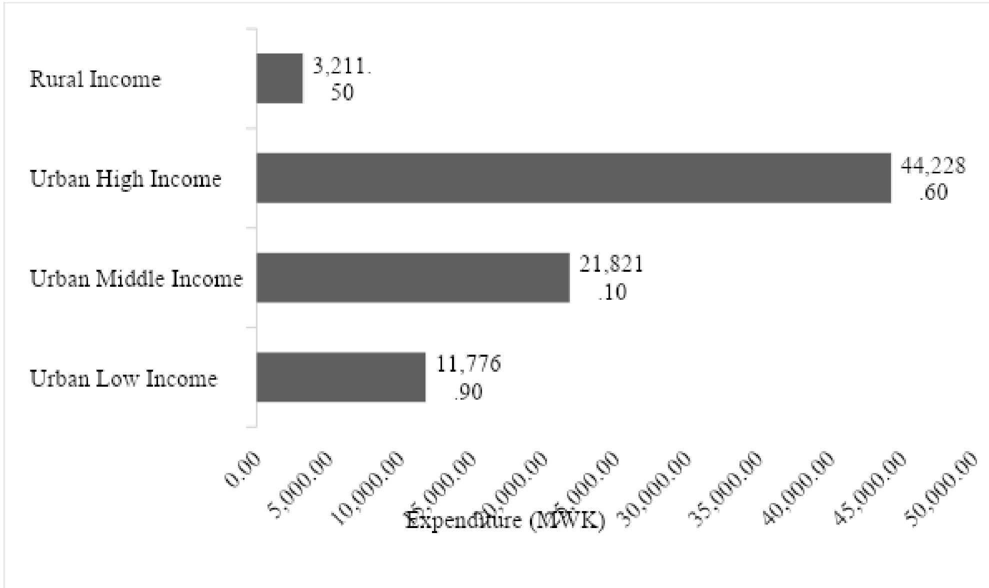


Figure 16 : Average monthly energy expenditure by area

b) Choice of Cooking Fuels

In most households interviewed, fuel stacking was observed. The use of multiple fuels is almost used in many households across the SSA region (Alexander et al., 2018). 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. In rural households, stacks of firewood and charcoal were observed. Meanwhile, in urban households, a combination of electrical, LPG, charcoal, or firewood cooking appliances were observed which was suggestive of urban fuel stacking. 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 (Shupler et al., 2019).

The top 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 the Africa and other continents (Serrano-Medrano et al., 2019). 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%). Nguyen & Ngo (2019) suggests that 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 makes the household to understand various fuels available for adoption.

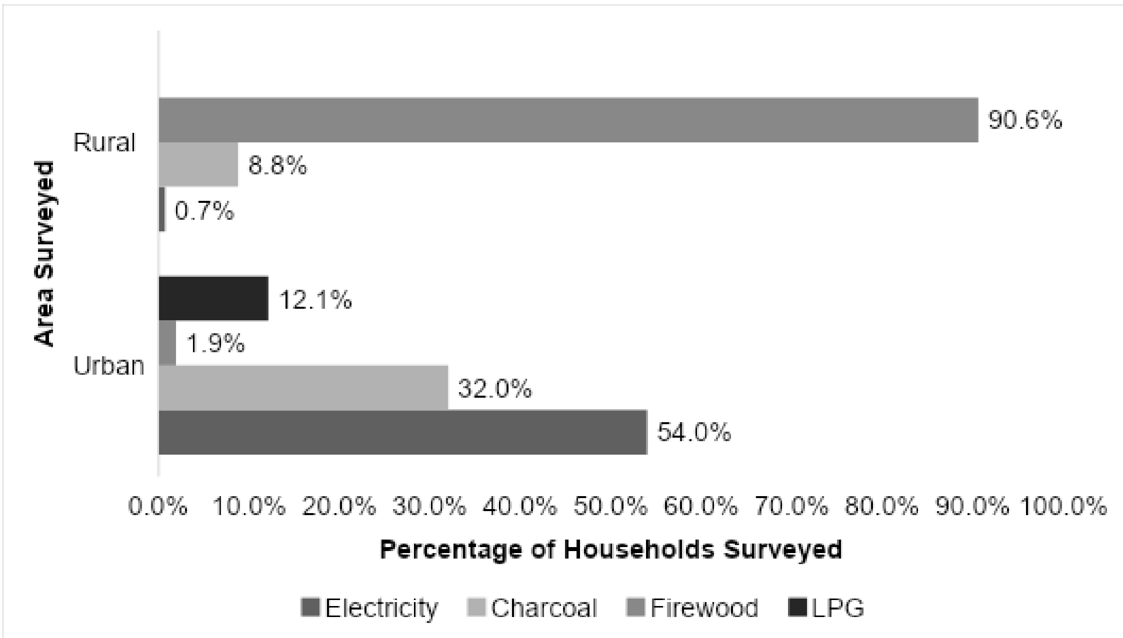


Figure 17 : Household cooking fuel preference by area

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 (Fig. 17). Semenya, and Machete (2019) 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 high-income preference of cooking electricity is associated with high income levels as are able to afford cooking on electricity (Fig. 18). 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.

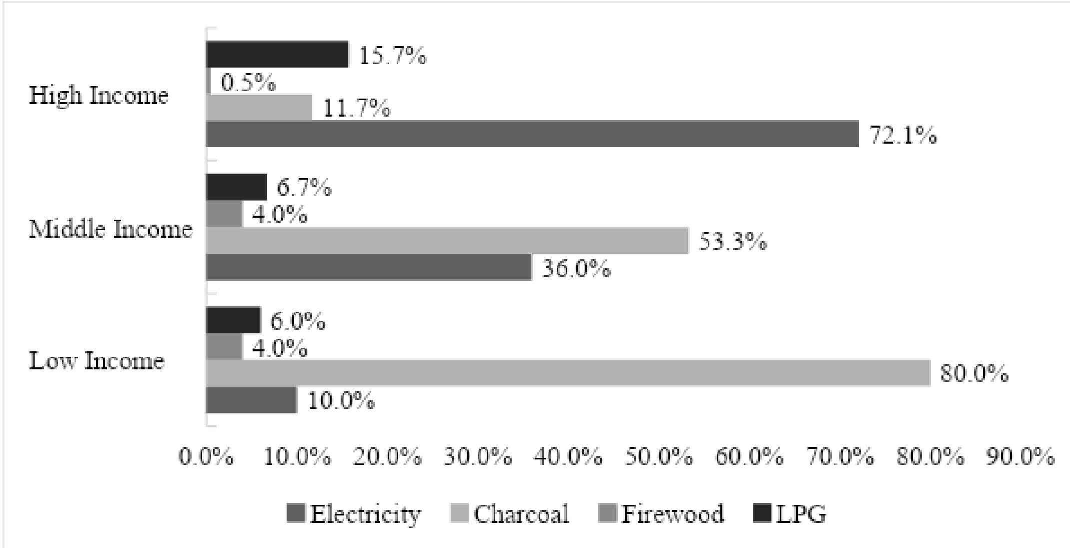


Figure 18 : Urban Household Cooking Fuel Preference by Income Level

The survey collected urban respondents' rationale behind their top cooking fuel preference. Table 14 displays that whether 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 when compared with other fuels under research.

Table 14: 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

The households cooking fuel preference results are presented in Table 15 below:

Table 15 : Household preference 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 (Sepp, 2014). 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 d preference fuel is jeopardized considering such factors.

c) Cooking Appliances

The research 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 area. For rural areas, the most commonly available fuel is firewood; therefore, most of the rural respondent's report using a three-stone fire (68%) to cook. In rural areas, improved firewood cookstoves 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, most low-income respondents reported using a charcoal stove, specifically the Jiko (88%), while most 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.

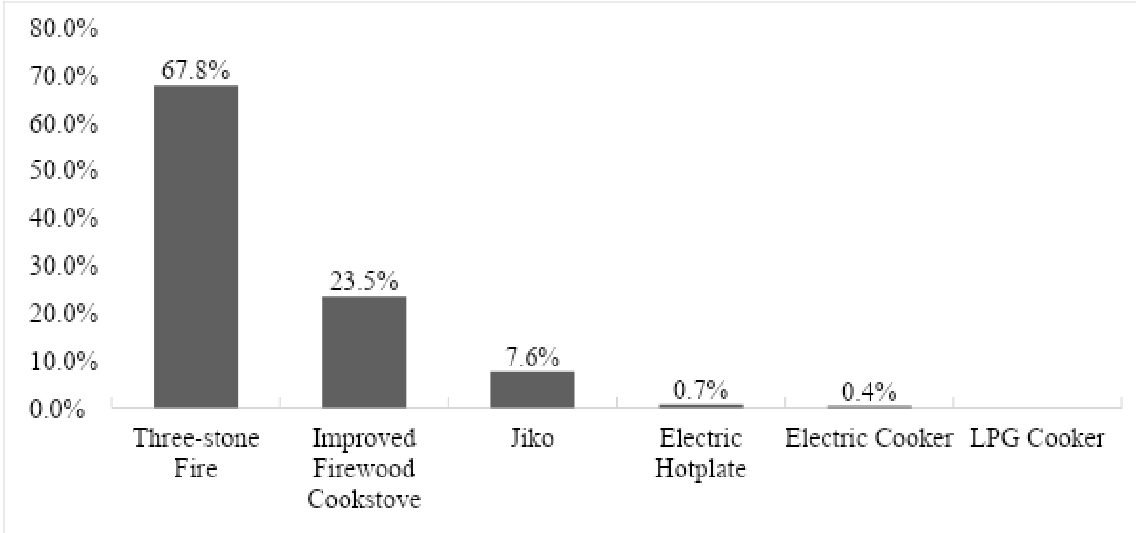


Figure 19 : Rural Household Cooking Appliances

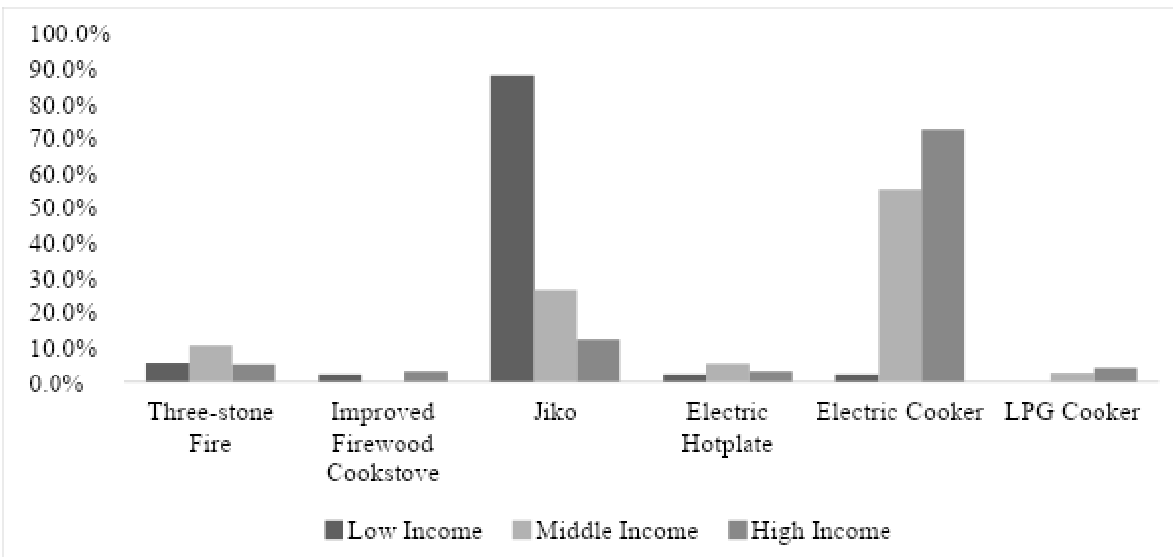


Figure 20 : Urban Household Cooking Appliances

d) 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 21 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.

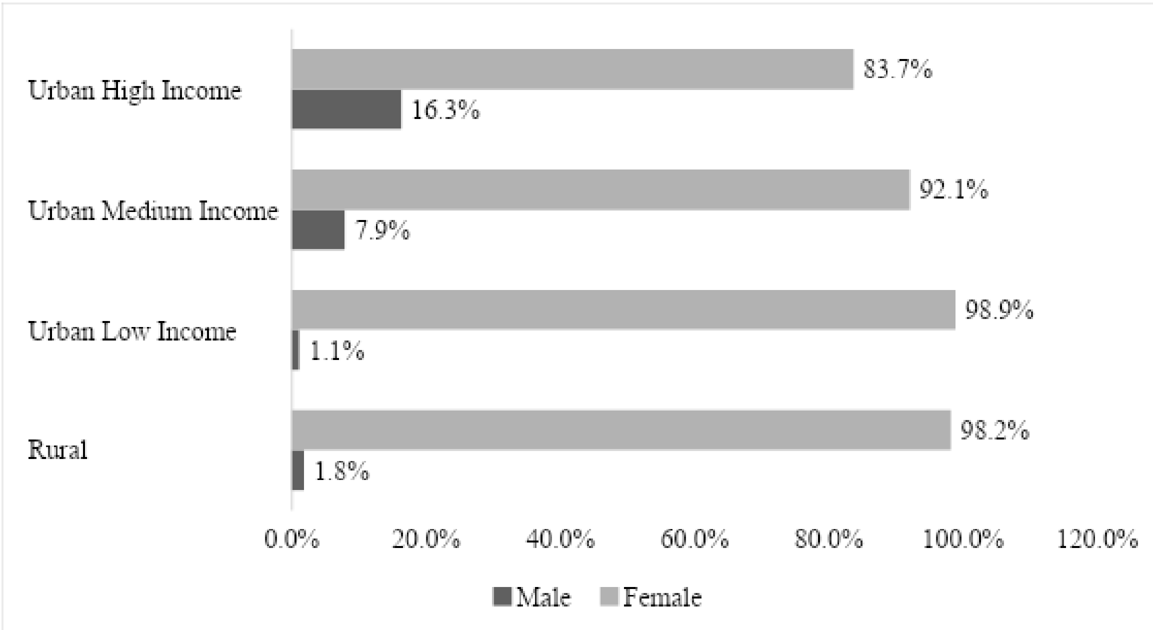


Figure 21 : Gender of household cook by area and income level

4.3. Objective 2: To deduce the efficiency of LPG as compared to other available cooking fuel alternatives (electricity, charcoal, firewood) in Malawi

4.3.1 Controlled Laboratory Tests

4.3.1.1 Comparative 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 shown in Table 6. The T-test results showed no significant difference in t_{bT} between these two stoves. However, there were significant differences in η_T, MWK/WBT and TDR. 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.

Table 16 : Performance for Chitetezo Mbaula and Three- Stone fire

	Units	Chitetezo Mbaula			Three-Stone			Statistics	
		Mean	**SD**	**COV**	**Mean**	**SD**	**COV**	**P Value**	**P<0.05**
Temperature corrected-Time to boil	Min	14.7	0.37	2.5%	16.6	1.40	8.4%	0.192	NO
Thermal efficiency	%	25.3	0.25	1.0%	10.7	1.00	9.3%	0.001	YES
Cost per WBT of 1.5 Litres	MWK/WBT	25.5	2.00	7.8%	40.6	4.83	11.9%	0.033	YES
Turndown Ratio	-	1.5	0.02	1.1%	3.1	0.50	16.3%	0.049	YES

The WBT results for the charcoal-burning Jiko and Envirofit stoves were similar and are presented in Table 7. 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. 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. This 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.

Table 17 **:** Performance metrics for Envirofit and Jiko Stoves

Variable	Units	Envirofit (KC)			Jiko (KC)			Statistics	
		Mean	**SD**	**COV**	**Mean**	**SD**	**COV**	**T-Test**	**Significant @ 95% Confiden**
Temperature corrected time to boil	Min	15.1	0.6	3.9%	24.7	0.3	1.4%	2.00E-04	YES

Thermal efficiency	%	23.2	1.3	5.5%	18.6	0.5	2.5%	0.026	YES
Cost per WBT of 1.5 Litres	MWK /WBT	52.7	2.1	4.0%	60.3	2.3	3.8%	0.026	YES
Turndown ratio		1.94	0.2	12.2%	1	0	3.1%	0.029	YES

4.3.1.2 Comparative performance of local charcoal and Kawandama Hills Plantation Charcoal

Next, the controlled laboratory testing compared local charcoal to Kawandama Hills Plantation charcoal. Table 18 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 18 : Performance Metrics for Kawandama Hills Charcoal and Local Charcoal When Burned in Envirofit Stove

	Units	**Local Charcoal**			**KHP Charcoal**				
		Mean	**SD**	**COV**	**Mean**	**SD**	**COV**	**P Value**	**P<0.05**
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

4.3.1.3 Comparative Thermal Efficiency Tests of Cooking Appliances

A one factor ANOVA was done to compare all cooking appliances in the research. 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 Fig. 22, the findings of the research 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.

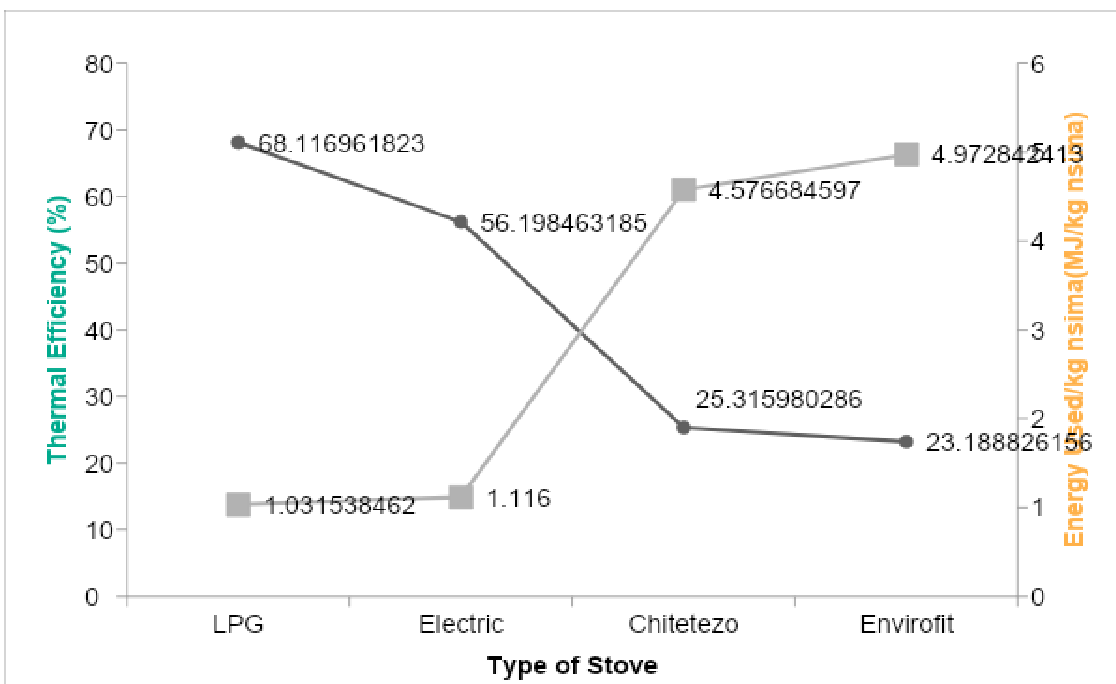


Figure 22 : Thermal Efficiencies and Energy Use of different stoves

Furthermore, LPG as a cooking fuel exceeded other fuel types in terms of cooking time. Figure 23 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 9 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 19).

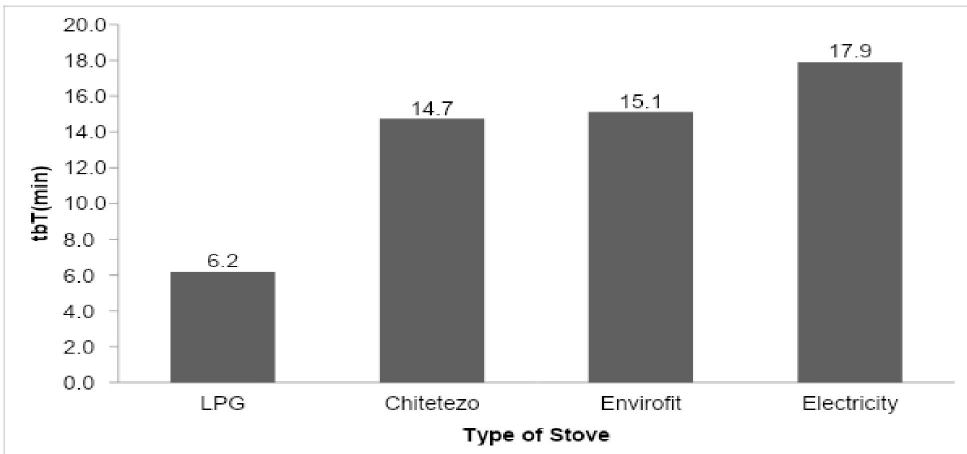


Figure 23 : Time Effectiveness of different stoves

Table 19 : 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
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 Figures 22 and 23 coupled with the data presented in Table 19 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 9). 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 to attain the desired power level. Sustaining a desired power level is also difficult to achieve with the Envirofit.

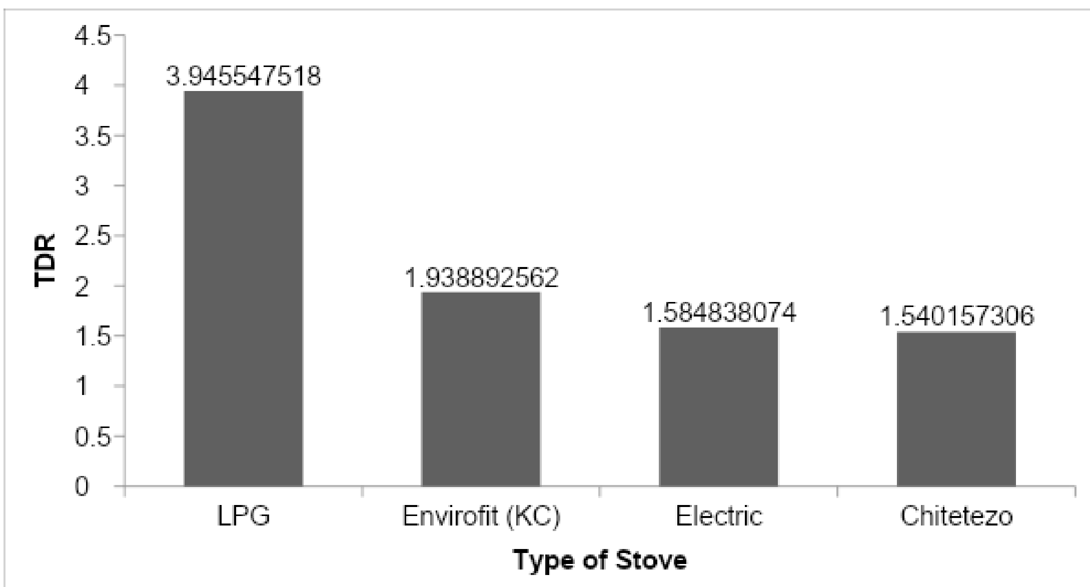


Figure 24 : Comparison of turndown ratios of different stoves

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 25). From Table 20, 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.

Table 20 : Fuel Cost Calculations at Time of Research

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 21 : Fuel costs at time of research

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

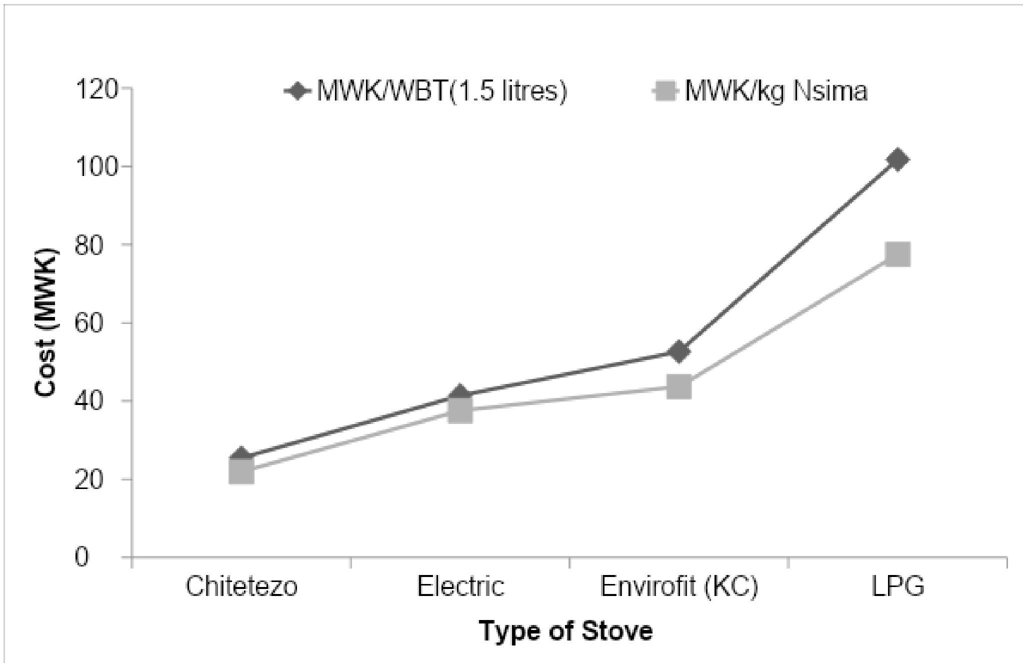


Figure 25 : Cost effectiveness of firewood in a chitetezo Mbaula, Electricity, Kawandama hills Plantation Charcoal in an Envirofit and LPG Stoves

4.3.1.4 Fuel Emissions Tests

All the stoves used in the controlled laboratory tests had similar greenhouse gas emission outputs except for the LPG stove which did not emit Carbon monoxide (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 research conducted by Johnston et al. (2019). Also interesting to note is that the Envirofit stove emitted less SO_2 when burning the Kawandama Hills Plantation Charcoal than when burning local charcoal. Results are shown in Table 12 below. The research suggests further research to determine if the process of production of Kawandama Hills Plantation Charcoal has an effect on the level of emissions produced at cooking.

Table 22 **: Fuel emissions 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 CO recorded by gas detectors varied with the vertical distance between the detector and the stove as seen in Table 1s3 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.

Table 23: Table 13: 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

4.4 LPG RESEARCH MODEL

Figure 22 below shows an LPG framework model developed from this research, it shows the major actors for the successful adoption of LPG in households and institutions.

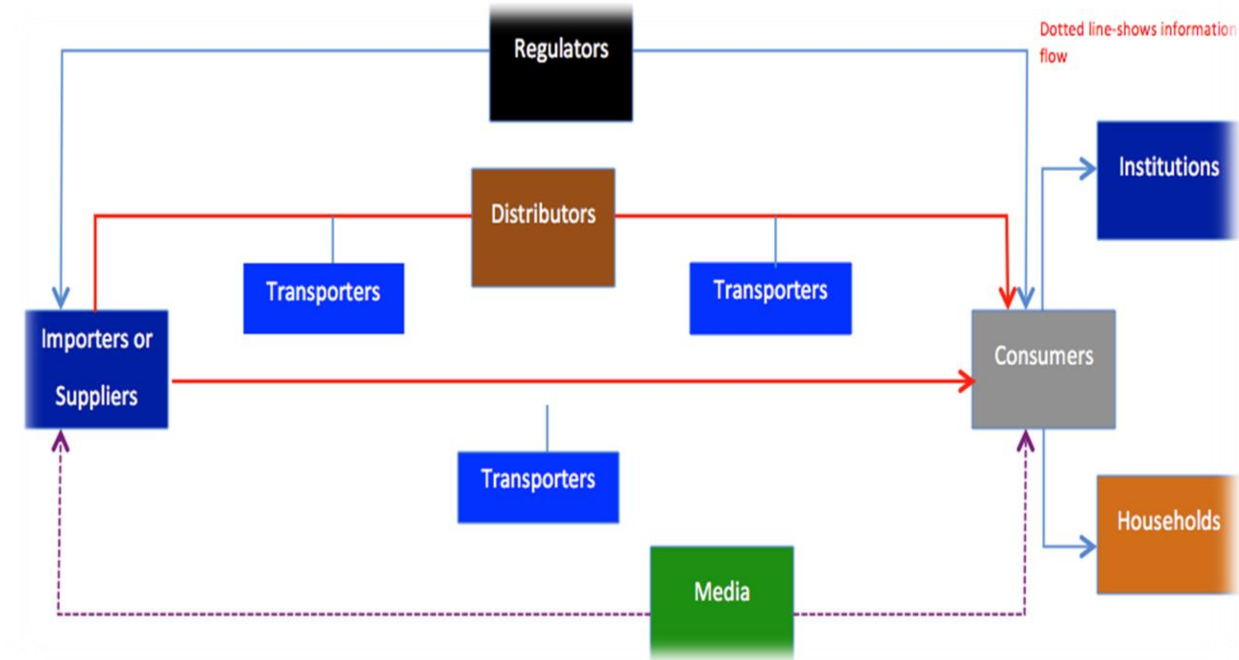


Figure 26: LPG Research Model

The actors presented such as transporters are key for the LPG supply in the country, when LPG reaches the country it is regulated by MERA, in addition suppliers, distributors and consumers are key for massive adoption of LPG.

CHAPTER: 5 CONCLUSION AND RECOMMENDATIONS

The preferences, willingness to pay, and market research on LPG offers useful information on the cost, market potential and efficiency of cooking fuels as well as cooking appliances used in Malawi. This information can encourage changes in the domestic energy sector that may increase LPG uptake as an alternative cooking fuel and improve the supply and regulatory environment for LPG within Malawi. The analysis conducted has established that LPG is a more efficient cooking fuel when compared to other common fuels used in Malawi. However, there are barriers to LPG use, including inadequate knowledge about its efficiency as well as safety and cost concerns. Historically, the negative perceptions and low distribution of LPG have limited the alternative fuel's adoption. These barriers have, thus, also impeded achievement of the Government of Malawi's National Charcoal Strategy ambitions. The recommendations below have been summarized from the various sections of this research.

5.1 For urban households, the research recommends that efforts should be made to promote LPG as an alternative cooking fuel. LPG was found to be more efficient than electricity and charcoal, the two most preferred cooking fuels in urban areas currently. Due to the current underdeveloped LPG distribution network and the low rural energy expenses recorded among rural households, the researcher does not recommend targeting rural Malawians for LPG adoption.

5.2 The research found there is inadequate knowledge about LPG cooking fuel efficiency and cost. In addition, there is a 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.

5.3 The research found that low uptake of LPG could be attributed to barriers related to market entry and affordability of LPG for potential consumers, such as high cost of canisters. It is, therefore, recommended that distributors introduce smaller LPG canisters and offer credit lines on cylinders to encourage more households to adopt and use LPG as their primary cooking fuel.

5.4 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.

5.5 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.

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APPENDICES

Appendix A: Institutional Questionnaire

□ **IMPORTANT NOTE TO ENUMERATOR:** Please get consent BEFORE you start filling in the questionnaire

Hello, my name is ___________I am working with **Admore Chiumia a Master of Philosophy in Applied Science Student activity under University of Malawi Polytechnic**. Your company been chosen to participate in this research. We are conducting a Quantitative and Qualitative Market Research for Liquefied Petroleum Gas (LPG) in Malawi. The survey is a confidential exercise and the name of your company 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?

If **NO**, mark here ☐ end of the interview.

If **YES**, mark here ☐ to acknowledge that consent from the respondent was provided

SECTION 1	**DEMAND / CONSUMPTION**	**SKIP**
Q1.1	Do you have access to the following energy sources? (Enumerator: Read ALL types of energy) **CODE: YES=1, NO= 2**	

#	**TYPE OF ENERGY**	**RESPONSE CODE**	
1	Electricity		MULTIPLE RESPONSES POSSIBLE
2	Charcoal		
3	Fuel wood		
4	Biogas		
5	LPG		
6	Solar		
7	Petroleum products (Petrol/Diesel/Paraffin)		
8	Others (specify)		

Q1.2

How do you use each of the selected energy sources to Q1.1?

CODE: YES=1, NO= 2

TYPE OF ENERGY	HOW EACH TYPE OF ENERGY IS USED				
	Cooking	Heating	Lighting	Others (specify)	MULT LE RESPO SES POSSI LE
Electricity					
Charcoal					
Fuel wood					
Biogas					
LPG					
Solar					
Battery torch					
Others (specify)					

Q1.3

Rank the energy sources you normally use in order of preference starting with 1, as the most preferred energy source?

#	TYPE OF ENERGY	COOKING	HEATING	LIGHTING	RANK IN ORDER OF PREFRENCE
1	Electricity				
2	Charcoal				
3	Fuel wood				
4	Biogas				
5	LPG				
6	Solar				
7	Battery torch				
8	Others (specify)				

Q1.4

Give reasons for the top energy sources that you prefer most?

#	USE	TYPE OF ENERGY	REASONS WHY PREFERRED (RESPONSE CODES)	RANK YOUR REASONS IN ORDER OF IMPORTANCE	
1	Cooking			1. 2. 3.	MULTIPLE RESPONSES POSSIBLE
2	Heating			1. 2. 3.	
3	Lighting			1. 2. 3.	

RESPONSE CODE:

REASONS WHY THEY ARE PREFERED	CODES	
Locally available or accessible	1	MULTIPLE RESPONSES POSSIBLE
Cheap or affordable	2	
Have knowledge about how to use them	3	
Safe to use	4	
The food taste better	5	
Others (specify)	6	

Q1.5	How would rank the cooking fuels in terms affordability? (1 indicates the most affordable fuel)	
Q1.6	What are the estimated monthly volumes you use of each type of fuel and their cost?	
Q1.7	What made you start using LPG?	

Q1.5

#	TYPE OF ENERGY	RANK
1	Electricity	
2	Charcoal	
3	Fuel wood	
4	Biogas	
5	LPG	
6	Solar	
7	Battery torch	
8	Others (specify)	

Q1.6

#	TYPE OF ENERGY	VOLUME	COST
1	Electricity		
2	Charcoal		
3	Fuel wood		
4	Biogas		
5	LPG		
6	Solar		
7	Battery torch		
8	Others (specify)		

Q1.7

#	REASONS FOR USING LPG	CODE	RESPO ES COD
1	Intermittent ESCOM Power Supply	1	
2	Not being connected to the main power grid line	2	
3	Scarcity of biomass energy	3	

4	Price of biomass energy	4		
5	Healthy and environmental benefits	5		
6	Efficient	7		
7	Others specify	8		

Q1.8 What type of LPG equipment do you have?

LPG Equipment	**Capacity (kg/litres)**			
Filled cylinder				
Unfilled cylinder				
LPG Stove/Cooker				
LPG Fridge				
Others (Specify)				

Q1.9 Where do you buy your LPG? **Multiple responses allowed**

#	**SOURCE OF LPG**	**LIST OF LPG SUPPLIERS**
1	Imported	
2	Locally	
3	Others (specify)	

Q1.10 What are the reasons why you buy from your preferred supplier?

#	**SOURCE OF LPG**	**RANK**
1	Cheap	
2	Credit facility available	
3	Good after sales support	
4	Free installation	
5	End user training	
6	Proximity	
6	Reliability/Always have stock	
3	Others (specify)	

Q1.11	Do you have contracts with suppliers of LPG? Give a reason for your answer?	
Q1.12	What has been the price of refilling an LPG cylinder for the past three years?	

	<table><tr><td>Capacity of cylinder</td><td>2017</td><td>2016</td><td>2015</td></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr></table>(Hint: take note of the size)	
Q1.13	At what intervals do refill you LPG cylinder?	
Q1.14	What are the sources of funds for buying LPG? <table><tr><td>**#**</td><td>**SOURCE OF FUNDING**</td><td>**CODE**</td><td>**RESPONSES CODE**</td><td>**RANK**</td><td rowspan="5">**MULTIPLE RESPONSES ALLOWED**</td></tr><tr><td>1</td><td>Own funds</td><td>1</td><td></td><td></td></tr><tr><td>2</td><td>Government</td><td>2</td><td></td><td></td></tr><tr><td>3</td><td>Donor</td><td>3</td><td></td><td></td></tr><tr><td>8</td><td>Others specify</td><td>4</td><td></td><td></td></tr></table>	
Q1.15a	Do you plan to increase your usage of LPG? ☐ Yes ☐ No	
Q1.15b	Why do you plan to increase usage of LPG? <table><tr><td>**#**</td><td>**REASONS FOR USING LPG**</td><td>**CODE**</td><td>**RESPONSES CODE**</td></tr><tr><td>1</td><td>Intermittent ESCOM Power Supply</td><td>1</td><td></td></tr><tr><td>2</td><td>Not being connected to the main power grid line</td><td>2</td><td></td></tr><tr><td>3</td><td>Scarcity of biomass energy</td><td>3</td><td></td></tr><tr><td>4</td><td>Price of biomass energy</td><td>4</td><td></td></tr><tr><td>5</td><td>Healthy and environment benefits</td><td>5</td><td></td></tr><tr><td>6</td><td>Portable</td><td>6</td><td></td></tr></table>	

	7	Efficient	7		
	8	Others specify	8		
Q1.15c	How much do you intend to invest in the expansion? K______________				
Q1.15d	Why don't you wish to increase usage of LPG?				

#	**DISADVANTAGES IN USING LPG**	RESPONSE CODE	RESPONS
1	No need to increase usage	1	
2	Long distance to refill the cylinder	2	
3	Unavailability of LPG equipment locally	3	
4	Limited use of LPG equipment	4	
5	Lack of maintenance services of LPG equipment	5	
6	LPG is unsafe/dangerous	6	
7	Others specify	7	

Q1.16	What are some of the challenges you face in using LPG?	

PROBLEMS	**CODE**	**RESPONSE**
Availability of LPG	1	
Lack of finance	2	
Lack of LPG Equipment	3	
Lack of technical support	4	
Storage of LPG	5	
Lack of knowledge about LPG	6	
Lack of safety	7	
Others specify	8	

Q1.17	How are you currently managing some of the problems you face in using LPG?	
SECTION 2	**INFORMATION**	
Q2.1	What type of information do you need in using LPG?	

	TYPE OF INFORMATION	CODE	RESPONSE CODE	Multiple responses allowed	
	Price	1			
	Product	2			
	Suppliers of LPG and Equipment	3			
	Service providers	4			
	Others (specify)	5			
Q2.2	How do you get the information about LPG?				

TYPE OF INFORMATION	**CODE**	**RESPONSE CODE**
Print Media (newspapers)	1	
Emails	2	
Radio	3	
Television	4	
Social Media	5	
Word of Mouth	6	
Others (specify)	7	

SECTION3	**SERVICE PROVISION**	**SKIP**
Q3.1	What type of support services do you need?	

TYPE OF SUPPORT SERVICES	**CODE**	**RESPONSE**
Maintenance of LPG Equipment	1	
Disposal of LPG	2	
Storage of LPG	3	
Training in LPG for your staff	4	
Others specify	5	

Q3.2	Where do you source these support services?	

SOURCE OF SUPPORT SERVICES	**CODE**	**RESPONSE**
Suppliers	1	
Private service provide	2	

	Others specify	3	
Q3.3	What challenges do you experience in accessing these support services?		
	CHALLENGES	**CODE**	**RESPONSE**
	Expensive	1	
	Limited availability of spare parts	2	
	Limited technical expertise	3	
	Delays by service providers	4	
	Others specify	5	
Q3.4	What could be done to address the challenges you face in accessing support services?		
SECTION 4	**LPG POLICY AND REGULATIONS**		**SKIP**
Q4.1	Are you aware of any policies relating to safety standards regarding usage, storage, and disposal of LPG? YES NO		
Q4.2	How can we make these policies in Q4.1 known to Malawians?		
Q4.3	Which specific policies and regulations should be put in place to promote LPG in Malawi**?**		
Q4.4	How can we ensure that there is enforcement of these policies?		

THANK YOU VERY MUCH FOR YOUR TIME

Appendix B: Supplier Questionnaire: LPG Market Assessment

SECTION A: IDENTIFICATION
District (name): ____ CODE: |____|____| Traditional Authority/Town/City Location: __________________________ CODE: |____|____| Group Village Headman (name)_________________________________ CODE: |____|____| Village Name:____CODE: |____|____| Grid Reference Number: _____________________ Questionnaire Number: |____|____||____|____| D D M M Y YYY Date of interview |____|____||____|____||____|____|____|____|

IMPORTANT NOTE TO ENUMERATOR: Please get consent BEFORE you start filling in the questionnaire

Hello, my name is __________I am working with **Admore Chiumia a Master of Philosophy in Applied Science Student activity under University of Malawi Polytechnic**. Your company been chosen to participate in this research. We are conducting a Quantitative and Qualitative Market Research for Liquefied Petroleum Gas (LPG) in Malawi. The survey is a confidential exercise and the name of your company 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?

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

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

SECTION 1	**BASIC COMPANY& RESPONDENT INFORMATION**	**SKIP**

Q1.1	Sex of respondent (1=M; 2=F) ____	
Q1.2	Age of respondent: ___________	
Q1.3	What is the name of your company? ___________	
Q1.4	What is its primary commodity? ___________	
SECTION 2	**CURRENT STATE OF COMPANY**	**SKIP**
Q2.1	Is your business making a profit on the LPG front? YES NO	
Q2.2	How does that compare to one, three, and five years ago? Increased ☐ Decreased☐ Mixed ☐ Don't know☐	
Q2.3a	Do you see your revenues on LPG improving in the near future? YES NO	**If NO>> Q2.3c**
Q2.3b	Why do you think revenues will increase?	
Q2.3c	Why do you think revenues will increase?	

Q2.3b table:

#	ADVANTAGES OF LPG	RESPONSE CODE	RESPONSES
1	Reliable compared to ESCOM Per Supply	1	
2	Increase clientele base	2	
3	Increasing knowledge among households	3	
4	Less costly	4	
5	Others specify	5	

Q2.3c table:

#	ADVANTAGES OF LPG	RESPONSE CODE	RESPONSES

	<table><tr><td>1</td><td>Low clientele base</td><td>1</td><td></td></tr><tr><td>2</td><td>Expensive</td><td>2</td><td></td></tr><tr><td>3</td><td>Lack of knowledge among households</td><td>3</td><td></td></tr><tr><td>4</td><td></td><td>4</td><td></td></tr><tr><td>5</td><td>Others specify</td><td>5</td><td></td></tr></table>	
Q2.4	What is the state of your company's LPG Market?	
Q.2.5	Has competition increased or decreased over the last XX years? Increased ☐ Decreased ☐ No change☐ DON'T KNOW ☐	If YES>> Q2.7a If NO>> Q2.7b
Q2.6	Do you see a change in competition occurring soon?	
Q2.7a	Why do think competition has increased? <table><tr><th>#</th><th>REASONS FOR INCREASE IN COMPETITION</th><th>RESPONSE CODE</th><th>RESPONSES</th><th rowspan="6">MULTIPLE RESPONSES ALLOED</th></tr><tr><td>1</td><td>Increased participation by foreign firms</td><td>1</td><td></td></tr><tr><td>2</td><td>Entry of other local suppliers</td><td>2</td><td></td></tr><tr><td>3</td><td>Decrease in clientele base</td><td>3</td><td></td></tr><tr><td>4</td><td>Ease of importing materials</td><td>4</td><td></td></tr><tr><td>5</td><td>Others specify</td><td>5</td><td></td></tr></table>	
Q2.7b	Why do think competition has decreased? <table><tr><th>#</th><th>REASONS FOR DECREASE IN COMPETITION</th><th>RESPONSE CODE</th><th>RESPONSES</th><th rowspan="4">MULTIPLE RESPONSES ALLOWED</th></tr><tr><td>1</td><td>Decreased participation by foreign firms</td><td>1</td><td></td></tr><tr><td>2</td><td>Exit of other local suppliers</td><td>2</td><td></td></tr><tr><td>3</td><td>Increase in clientele base</td><td>3</td><td></td></tr></table>	

	4	Difficulty in importing materials	4			
	5	Others specify	5			
Q2.8	What is your competitive advantage over your competitors?					
Q2.9	Do your customers generally have a positive experience with your company's products or services?					
Q2.10	Is there anything you could do to improve your customer experience?					
SECTION 3	**LPG SALES AND MARKETING**					**SKIP**
Q3.1	When did you start selling LPG in Malawi?					
Q3.2	How do you access LPG Products ?					

Products	**Manufactured by my company locally**	**Imported**	**Buy from local suppliers/importers**
LPG Gas			
LPG Stove/Cooker			
LPG Fridge			
Cylinder			

	Others (Specify)				

Q3.3	If the LPG Products are imported, where are they imported from?
Q.3.4	If you import the LPG Products (Gas and equipment/appliances), what has been the value of imports for the past three years?

Products	**2016**	**2015**	**2014**
	MK	MK	MK
LPG Gas			
LPG Stove/Cooker			
LPG Fridge			
Cylinder			
Others (Specify)			

Q3.5 What are the capacities of LPG products you sell?

LPG Products	**Capacity (kg/litres)**			
LPG Gas				
LPG Stove/Cooker				
LPG Fridge				
Cylinder				
Others (Specify)				

Q3.6 a) Rank the LPG products in order of demand by individual households?

LPG Products	**Rank in order of Market Demand**			
LPG Stove/Cooker				
LPG Fridge				
Others (Specify)				

b) Give reasons why you think they are on high demand by individual households?

Q3.7 What has been the price of LPG Products for the past three years?

LPG Products	**PRICE PER YEAR**

		2016	2015	2014	
	GAS				
	Cylinder				
	LPG Stove/ Cooker				
	LPG Fridge				
	Other Specify				

Q3.8	Is the price for LPG standard or uniform across the country? Yes NO	
Q3.9	If no to Q3.8, what is the basis for price differentiation and how is it calculated?	
Q3.11	How much LPG do you sell per week/month/year?	

Week	Month	Year

Q3.12	What have been your sales volume/turnover for the past three years?	

LPG Products	YEAR		
	2016	**2015**	**2014**
GAS			
Cylinder			
LPG Stove/ Cooker			
LPG Fridge			
Other Specify			

Q3.13	Do you sell LPG products on credit? Yes no b) If yes, explain the credit terms (interest, duration etc)	

Q3.14	What do the majority of your main customers use LPG for?	

#	**Uses of LPG**	RESPONSE CODE	Response
1	Cooking	1	
2	Heating	2	
3	Lighting	3	
4	Cooling or refrigeration	4	
5	Transport	5	
6	Others (specify)	6	

Q3.15	Who are your frequent customers? (Rank your frequent customers in order of importance on a scale of 1 to 10 where 1 represents the most important category and 10 least important)	

	Customer Categories	**Rank**	**Proportion of the total sales from each of the customers**
1	Individual Households		
2	Restaurants		
3	Lodges		
4	Large Corporate /Private Institutions		
5	NGOs / Development Partners		
6	Government and its departments		
7	Exports (international market)		
8	Others (Specify)		

Q3.16	What category of individual customer segments constitutes the majority of the total household sales?	

#	**Individual Customer Segments**	**Rank**	**Proportion of total sales**

<table>
<tr><td></td><td><table><tr><td>1</td><td>Foreigners</td><td></td><td></td></tr><tr><td>2</td><td>Urban based Malawians</td><td></td><td></td></tr><tr><td>3</td><td>Peri –urban based Malawians</td><td></td><td></td></tr><tr><td>4</td><td>Rural – based Malawians</td><td></td><td></td></tr><tr><td>5</td><td>Others (specify)</td><td></td><td></td></tr></table>Give reason(s) for your answer?</td><td></td></tr>
<tr><td>Q3.17</td><td>If you export LPGs, how much is exported from Malawi?</td><td></td></tr>
<tr><td>Q3.18</td><td>Where are they exported to?</td><td></td></tr>
<tr><td>Q3.19</td><td>Are you involved in refinery?
YES NO</td><td></td></tr>
<tr><td>Q3.20</td><td>If you import LPG Products, how easy is it in terms of time, payment and transporting of LPG into Malawi?
Very Easy
Difficult Very difficult</td><td></td></tr>
<tr><td>Q3.21</td><td>How much LPG in tonnesdoes you import/produce/supply per week/month/year?<table><tr><td></td><td>Import</td><td>Produce</td><td>Supply</td></tr><tr><td>Week</td><td></td><td></td><td></td></tr><tr><td>Month</td><td></td><td></td><td></td></tr><tr><td>Year</td><td></td><td></td><td></td></tr></table></td><td></td></tr>
<tr><td>Q3.21b</td><td>If demand increase, would you be able to increase the volume you import/produce/supply per week/month/year?<table><tr><td></td><td>Import</td><td>Produce</td><td>Supply</td></tr><tr><td></td><td></td><td></td><td></td></tr></table></td><td></td></tr>
<tr><td>Q3.22</td><td>How long (Days/months) does it take you to have all the LPG imported or produced sold off?</td><td></td></tr>
</table>

<table>
<tr><td>Q3.23</td><td>List the sectors where LPG is mostly used in Malawi and rank them in order of importance on a scale of 1 to 5, with 1 representing the sector where is it is mostly used and 5 for the sector where it is least used?
<table>
<tr><td>#</td><td>Sector</td><td>Rank</td></tr>
<tr><td>1</td><td>Agriculture</td><td></td></tr>
<tr><td>2</td><td>Health</td><td></td></tr>
<tr><td>3</td><td>Transport</td><td></td></tr>
<tr><td>4</td><td>Tourism</td><td></td></tr>
<tr><td>5</td><td>Others (specify)</td><td></td></tr>
</table></td><td></td></tr>
<tr><td>Q3.24</td><td>Are there any plans expansion plans for your LPG business?
Yes No
Give reason(s) for your answer?</td><td></td></tr>
<tr><td>Q3.25</td><td>Explain the specific future plans of your LPG business?
Forecasted LPG Sales Volume or Growthfor the next four years?
<table>
<tr><td>LPG Product</td><td>2017</td><td>2018</td><td>2019</td><td>2020</td></tr>
<tr><td>GAS</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cylinder</td><td></td><td></td><td></td><td></td></tr>
<tr><td>LPG Stove/ Cooker</td><td></td><td></td><td></td><td></td></tr>
<tr><td>LPG Fridge</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other Specify</td><td></td><td></td><td></td><td></td></tr>
</table>
LPG Product Diversification
Share Market</td><td></td></tr>
<tr><td>Q3.26</td><td>Are you willing to import more if consumers pre-ordered?</td><td></td></tr>
<tr><td>Q3.27</td><td>How do you transport LPG:
From your sources?
To your customers?</td><td></td></tr>
</table>

<table>
<tr><td>Q3.28</td><td>How many selling/filling points do you have?</td><td></td></tr>
<tr><td>Q3.29</td><td>Do you offer any services to your customers?
Yes No</td><td>If No Skip to Q3.32</td></tr>
<tr><td>Q3.30</td><td>What type of services do you offer to your customers?
<table>
<tr><td>#</td><td>SERVICES</td><td>RESPONSES</td><td rowspan="6">MULTIPLE RESPONSES POSSIBLE</td></tr>
<tr><td>1</td><td>Installation</td><td></td></tr>
<tr><td>2</td><td>Training</td><td></td></tr>
<tr><td>3</td><td>Repair and Maintenance</td><td></td></tr>
<tr><td>4</td><td>Home delivery of LPG</td><td></td></tr>
<tr><td>5</td><td>Others (Specify)</td><td></td></tr>
</table>
RESPONSE CODES
<table>
<tr><td>SERVICES</td><td>CODES</td></tr>
<tr><td>Installation</td><td>1</td></tr>
<tr><td>Training</td><td>2</td></tr>
<tr><td>Repair and Maintenance</td><td>3</td></tr>
<tr><td>Home delivery of LPG</td><td>4</td></tr>
<tr><td>Others (Specify)</td><td>5</td></tr>
</table></td><td></td></tr>
<tr><td>Q3.31</td><td>If you don’t offer any of the above services, where else do your customers get them?</td><td></td></tr>
<tr><td>Q3.32</td><td>What are the effective marketing channels for LPG?
<table>
<tr><td>#</td><td>Marketing Channels</td><td>Response</td><td rowspan="9">Multiple Responses Possible</td></tr>
<tr><td>1</td><td>Face to face meetings</td><td></td></tr>
<tr><td>2</td><td>Radio</td><td></td></tr>
<tr><td>3</td><td>Television</td><td></td></tr>
<tr><td>4</td><td>Print media (Newspapers)</td><td></td></tr>
<tr><td>5</td><td>Mobile phones</td><td></td></tr>
<tr><td>6</td><td>Theatre for change (drama)</td><td></td></tr>
<tr><td>7</td><td>Billboards</td><td></td></tr>
<tr><td>8</td><td>Roadshows</td><td></td></tr>
</table></td><td></td></tr>
</table>

	9	Sponsorship events e.g. Golf tournaments	
	10	Others (specify)	

RESPONSE CODE

Marketing Channels	**CODE**
Face to face meetings	1
Radio	2
Television	3
Print media (Newspapers)	4
Mobile phones	5
Theatre for change (Drama)	6
Billboards	7
Roadshows	8
Sponsorship events e.g. Golf tournaments	9
Others (specify)	10

Q3.33

What do you think are some of the reasons for the poor development of the LPG industry in Malawi? Why most households do not use LPG?

#	**Reasons for underdevelopment of LPG Industry**	**Response**	MULTIPLE RESPONSE POSSIBLE
1	Lack of information		
2	Availability of LPG		
3	High Initial Investment Cost		
4	Availability of cheap alternative Energy Sources		
5	Poor Road Network		
6	Lack of LPG Storage Facilities		
7	Other (specify)		

RESPONSE CODE

Reasons for underdevelopment of LPG Industry	**CODE**

	Lack of information — 1 Availability of LPG — 2 High Initial Investment Cost — 3 Availability of cheap alternative Energy Sources — 4 Poor Road Network — 5 Lack of LPG Storage Facilities — 6 Other (specify) — 7	
Q3.34	How can LPG adoption be promoted in Malawi?	
Q3.35	What are your biggest challenges as an LPG supplier?	
SECTION 4	**LPG AND GENDER**	
Q4.1	In terms of gender, who are your main customers for LPG at household level? Men Female	
Q4.2	Do you think, females and males have the same access and capacity to LPG? Yes No	If yes, skip Q4.2 to Q5.1
Q4.3	If no to Q4.2, what should be done to promote women access to LPG?	
SECTION 5	**LPG POLICY AND REGULATIONS**	**SKIP**
Q5.1	ARE YOU AWARE OF ANY SAFETY STANDARDS REGARDING USAGE, STORAGE, AND DISPOSAL of LPG?	
Q5.2	HOW CAN WE MAKE THESE POLICIES IN Q4.1 KNOWN TO MALAWIANS?	
Q5.3	WHICH SPECIFIC POLICIES AND REGULATIONS SHOULD BE PUT IN PLACE TO PROMOTE LPG IN MALAWI**?** HOW CAN WE ENSURE THAT THERE IS ENFORCEMENT OF THESE POLICIES	

Appendix C: Regulators (Key Informant Interview) Questionnaire

Hello, my name is **___________**I am working with **Admore Chiumia a Master of Philosophy in Applied Science Student activity under University of Malawi Polytechnic**. Your company been chosen to participate in this research. We are conducting a Quantitative and Qualitative Market Research for Liquefied Petroleum Gas (LPG) in Malawi. The survey is a confidential exercise and the name of your company 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? Yes/No

Policy Makers and Regulators Discussion points

#	
1	What is your general perception of Liquefied Petroleum Gas use in Malawi compared to other countries?
2	Do you think LPG has realistic prospects of uptake by consumers?
3	What do you think are the main challenges in promoting LPG in Malawi?
4	How can we overcome these challenges?
5	What specific policies should be put in place to improve the competitiveness of LPG against other unsustainable energy options with an aim of promoting its use in Malawi?
6	What interventions are there to reduce or stop the demand of biomass fuels and promote use of liquid fuels?
7	What are your views on taxation of charcoal in urban areas to reduce its use?
8	What is your opinion on use of subsidies to promote LPG usage?
9	How can a subsidy programme be best implemented to avoid LPG market distortions?
10	What systems could be put in place to educate, review and oversee the adoption of good practices in LPG usage?
11	Elaborate the type of incentives that can be put in place to attract private investment in the LPG Market e.g. gas to go to remote villages and distribute gas to the rural communities periodically?

12	What roles can women play in the LPG sector and how can their participation be promoted?
13	What role can MRA play in to support the promotion and adoption of LPG in Malawi?

Thank you very much for your time

Appendix D: Pictures taken during the research

D1: Test rig during WBT for ceramic jiko burning local charcoal. Digital thermal and k-type thermocouple probed into the water are shown.

D2: A weighing scale used during the tests for measuring bigger mass quantities

D3: Controlled cooking test for chitetezo mbaula and 3-stone fire

Stoves from left to right: Envirofit, LPG stove, ceramic Jiko.

Bags of charcoal from right to left: Kawandama, local

Appendix E: Data capturing temperate customized for firewood

Ambient conditions		Test 1	Test 2	Test 3	CCT
	Temperature				
	RH				
Cold Start					
	Water Temperature Start				
	Mass of Pot				
	Mass of Pot + water (start)				
	Mass of charcoal container				
	mass of firewood (start)				
	time to boil				
	mass of unburned wood				
	mass of charcoal + stove				
	Mass of Pot + water (finish)				
Hot Start					
	mass of pot				
	Mass of pot + water (start)				
	Mass of wood (start)				
	Water Temperature (Start)				
	time to boil				
	mass of wood (finish)				
	mass of water + pot (finish)				
Low power					
	Temperature of water (start)				
	Time of simmering				
	Temperature of water (finish)				
	Mass of water + pot (finish)				
	Mass of unburned wood				
	Mass of charcoal + stove				

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.

7.1.1. 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):**

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

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 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:

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

If 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.

Appendix F: Household Questionnaire

Hello, my name is __________I am working with **Admore Chiumia a Master of Philosophy in Applied Science Student activity under University of Malawi Polytechnic**. Your household has been randomly chosen to participate in this research. 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?

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

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

SECTION B: DEMOGRAPHY

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

Age of respondent: ___________

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

Number of Adult Men ( ) and Women ( )

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

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

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). Are 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)

Grid electricity (Yes / No)

3-Stone Fire (Yes / No)

Candles (Yes / No)

Paraffin (Yes / No)

Battery torch

Solar torch

Improved cook stove (Yes/No)

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**
