EVALUATION OF ETHANOL BRIQUETTES FOR DOMESTIC COOKING IN SOME AREAS OF LILONGWE, MALAWI

(MASTER OF ENVIRONMENTAL SCIENCE) THESIS

KELVIN BANDA CHOMANIKA

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MSc (ENVIRONMENTAL SCIENCE) THESIS

By

KELVIN BANDA CHOMANIKA

BSc (Physical Planning), Mzuzu University

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DECLARATION

This Thesis is my original work and it has not been submitted to any other institution for similar purposes. Acknowledgements have been duly made where other people's works have been used. I bear the responsibility for the contents of this work.

KELVIN BANDA CHOMANIKA

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Full Legal Name

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Signature

03/06/2022

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Date

CERTIFICATE OF APPROVAL

The undersigned certify that this Thesis represents the student's work and effort and has been submitted with our approval.

Signature____________________________________ Date_______________________

Vunain, E., PhD (Associate Professor)

Main Supervisor

Signature_____________________________________ Date______________________

Mlatho, J.S.P, PhD (Associate Professor)

Member Supervisory Committee

DEDICATION

This Thesis is dedicated to my parents, Mr. Paffett Chomanika and Mrs Iness Chitofu Chomanika for good parenting; and to my wife, Bertha Z. Chomanika for her love and support.

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ABSTRACT

Access to clean, affordable and sustainable energy is one of the greatest challenges that people in Malawi currently face. Inefficient combustion of charcoal emits high levels of pollutants hence the need to explore clean cooking fuels such as ethanol briquettes. The study assesses the technical performance, social-cultural aspects and the economic cost of using ethanol fuel. Water boiling tests, controlled cooking tests, emissions tests, cooking diaries, focus group discussions, market assessments and household surveys were conducted. Results of ethanol briquettes calorimetry showed 37.4 Mj/kg and 36.1 Mj/kg while charcoal had 23.79 Mj/kg and 22.47 Mj/kg for high and low heating values. Boiling 1 L of water was faster in Chitetezo Mbaula because ethanol briquettes contributed to high stove firepower. The controlled cooking tests showed no significant differences in the time taken to cook a meal in all the stoves and fuel combinations. However, the specific fuel consumptions and the rate of emissions were significant at 95% confidence level. The release of carbon monoxide and particulate matter from ethanol briquettes were below the World Health Organization benchmarks of 0.07 g/min and 0.15 mg/min, respectively. The cost of cooking a meal using ethanol briquettes is fairly low when the fuel is estimated at MK760/Kg as compared to charcoal. The study established that households preferred using multiple fuels than completely shifting to a new technology. The adoption of ethanol briquettes correlates at different strengths to technical, social-cultural and economic factors. The predictor variables in multiple regression positively influence adoption (R=.397) by 15.8%. The study recommends the establishment of vibrant policies and operation procedures aimed at regulating production, accessibility and market price of ethanol briquettes to encourage widespread adoption and sustained use.

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ACRONYMS AND ABBREVIATIONS

CCT	Controlled Cooking Test
HHV	High Heating Value
IAP	Indoor Air Pollution
KCJ	Kenyan Ceramic Jiko
LHV	Low Heating Value
LPG	Liquefied Petroleum Gas
MBS	Malawi Bureau of Standards
SDG	Sustainable Development Goal
WBT	Water Boiling Test
WHO	World Health Organisation

CHAPTER 1

INTRODUCTION

1.1 Chapter overview

This chapter discusses the global status of household cooking energy and the current cooking energy situation in Malawi. The problem statement, study objectives, research questions, hypotheses and justification are also discussed in this chapter. In general, this chapter highlights the organisation and lays the foundation of the study.

1.2 Background

1.2.1 Global status of alternative cooking energy

The global populace greatly relies on energy for their regular cooking or heating activities. About 2.8 billion people worldwide do not have access to clean, affordable and reliable cooking fuels while at least 2.5 billion exclusively use charcoal or firewood (Rahut *et al*., 2020). The households are unable to cook efficiently, cleanly, conveniently, reliably, safely, and affordably because they rely on firewood and charcoal (ESMAP, 2020). Clean cooking energy including Liquefied Petroleum Gas (LPG), biogas, ethanol/methanol, improved biomass briquettes, and electricity both grid and photovoltaic are not commonly used (Puzzolo *et al*., 2019). The use of biomass fuels worldwide has contributed to several problems. According to the World Health Organisation (WHO), about three and four million people worldwide die per annum due to illnesses caused by fumes and toxins that are released during the cooking process (Batchelor *et al.,* 2019; Quinn *et al*., 2018). To address the ongoing crisis, countries at global level are searching for alternative cooking energy solutions that either emit less or no pollutants into the atmosphere (UNDP, 2007). To attain the sustainable development goal number 7, the universal promotion to use better-quality cookstoves and clean fuels that are efficient and renewable is crucial (ESMAP, 2020; Rosenthal *et al*., 2018). Achieving the goal by the year 2030 would require a technology step-up and provision of more sources of clean energy for all (Quinn *et al.*, 2018).

1.2.2 The need for alternative clean cooking energy in Malawi

Malawi is a landlocked country located in the southern region of Sub Sahara Africa (Coley & Galloway, 2020). According to the National Charcoal Strategy [NCS] of Malawi, households above 97 percent dominantly use fuelwoods to meet their cooking energy needs (GoM, 2017). The substantial and continued use of fuelwoods is attributed to lack of availability, affordability and accessibility of clean cooking fuels (Putti *et al*., 2015). Recent studies have reported that most woodlands continue to be depleted due to the unsustainable production of charcoal in earth kilns (Bates *et al.,* 2011; Coley & Galloway, 2020). Moreover, the practice of cutting down trees wantonly for provision of cooking fuels have not only contributed to global warming and climate change but also to loss of biodiversity and environmental degradation (Sedano *et al.,* 2016; Taulo & Gondwe, 2015). It has been noted that burning of charcoal and fuelwoods have negative effects on respiratory health of human beings (Cundale *et al.*, 2017). Malawi has several alternative sources of clean cooking energy such as hydroelectricity, solar and biogas, liquefied petroleum gas and ethanol but they are not exclusively used (Robinson, 2006). The available clean energy sources are not sufficient hence not fully implemented to attract households at all levels to start using them (Taulo & Gondwe, 2015).

In Malawi, provision of hydroelectricity is affected by poor transmission as evidenced by substantial power outages (Kambewa & Chiwaula, 2010). Load shedding is usually scheduled at times of cooking or heating (Gamula *et al.*, 2013). This compels most households to use charcoal or firewood for cooking (Zalengera *et al*., 2014). Several legislations, policies and strategies like the Malawi Biomass Energy Strategy, National Charcoal Strategy, Malawi Renewable Energy Strategy, and National Energy Policy are available to control the high usage of biomass fuels that are both informally and illegally sold on the markets (Coley & Galloway, 2020). Therefore, it is important to come up with viable solutions of clean cooking energy.

1.2.3 Ethanol briquettes as clean cooking alternative

Ethanol has excited a lot of interest as a feasible alternative source of energy at a global level (Robinson, 2006). It has been long recognised that ethanol is a clean, eco-friendly green and effective fuel for cooking (Utria, 2004). Until recently, the fuel has only been marketed in liquid or gel forms which is not only hazardous when spillages occur but also require distinct appliances that are well-designed (Lloyd, 2014; Lloyd & Visagie, 2007). In Malawi, companies such as Bluewave and D&S Gel fuel have tried to test and promote ethanol for cooking using appliances such as SuperBlu, Clean Cook Stove and Gelfuel Stove, among others. Both the fuel and stove technologies were not user-friendly, un-safe and expensive hence facing resistance to widespread adoption (UNDP, 2007).

Ethanol briquettes are made by adding thickening agents for coagulation (BCB International, 2015). As a clean cooking alternative, the solidified fuel is deemed to be the most suitable energy option for safe and reliable cooking at the household level. Ethanol solidified with hydroxypropyl methylcellulose is more viscous, active and burns consistently (John *et al*., 2016). The briquettes are made from completely denatured alcohol, thereby making them sustainable, safe, reliable and suitable for cooking at the household level (Feng *et al*., 2019).

The present study has adapted, for use with ethanol briquettes, the local stoves of Chitetezo Mbaula and Kenya Ceramic Jiko for the reason that they are widely used for cooking in Malawi (Gamula *et al.*, 2014). The stoves have been retrofitted with simple and low-cost combustion chambers to burn ethanol briquettes without significant loss of heat. To achieve efficient cooking and significant reduction of indoor air pollution in the kitchens (Oketch, 2013), several parameters that might affect the technical performance of new stove prototypes paired with ethanol briquettes have been trailed and compared to charcoal. The study was therefore, aimed at implementing a designed and fabricated stove prototype for efficient and clean cooking using ethanol briquettes in Malawi.

1.3 Problem statement

Energy is essential for the sustenance of life, although millions of people worldwide are unable to meet their energy demands. In Africa, households suffer a shortage of affordable and clean cooking fuel alternatives (Quinn *et al.*, 2018). In Malawi, the use of ethanol gel fuels emerged as the best alternative for cooking (Robinson, 2006; UNDP, 2007). Ethanol in liquid or gel form spill easily because of poor quality stove technologies like SuperBlu and D&S hence failed to satisfy the cooking tasks of users (Stockes *et al*., 2010). Several stove technologies have been developed to burn ethanol briquettes but they are not suitable for most cooking practices and tasks in Malawi (BCB International, 2015). The stoves are both expensive and fancy hence a barrier to adoption especially in low- and middle-income countries (Puzzolo *et al*., 2019). The use of charcoal or firewood would remain high if the adoption of modern cooking solutions remain slow and face challenges (ESMAP, 2020). The present study has modified the existing low-cost stove models, such as the Chitetezo Mbaula and the Kenyan Ceramic Jiko and retrofit them with simple and low-cost containers to effectively burn ethanol briquettes without significant loss of heat. The research focuses on the evaluation of ethanol briquettes for domestic cooking in Malawi.

1.4 Research questions

The research questions used in this study are given below

i. How can ethanol fuel be retrofitted and paired with existing low-cost cookstoves for household cooking, and what is the efficiency of the fuel when paired with the cookstoves?
ii. What are the technical, economic and social-cultural factors that would affect the decision to adopt the technology?
iii. What are the differences between cooking costs associated with ethanol briquettes and charcoal?

1.5 Research objectives

1.5.1 Main objective

The main objective of study was to evaluate the technical, social-cultural and economic viability of large-scale adoption of ethanol briquettes by households in Malawi as an alternative to charcoal or firewood.

1.5.2 Specific objectives

The specific objectives of the study were to:

i. Assess the technical performance of ethanol briquettes and charcoal with different stove models to determine if existing models can be used with or without adaptations.

ii. Assess the social-cultural perceptions/experience of users to determine how the fuel and stoves fit into the cooking mix and the potential for adoption at large scale.

iii. Determine the economic cost of cooking with the ethanol fuel for a typical household compared with charcoal.

1.6 Study hypotheses

i. H_0: The performance and efficiency of charcoal and ethanol briquettes are not the same in all test stoves.

   H_1: The performance and efficiency of charcoal and ethanol briquettes are the same in all test stoves.

ii. H_0: Technical, social-cultural and economic factors do not significantly affect the household's decision to adopt and use ethanol briquettes.

   H_1: Technical, social-cultural and economic factors significantly affect the household's decision to adopt and use ethanol briquettes.

1.7 Justification of study

Energy for household cooking remains a topic of concern in all countries around the world. This study pursued to achieve the targets of sustainable development goal (SDG) number 7 on affordable and clean energy by providing access to alternative clean, modern and affordable cooking fuel and stoves in Malawi (Baltruschat, 2019). Besides, SDG 3 on good health and wellbeing, and number 13 on climate action have been tackled by coming up with less polluting fuel and stoves (Rosenthal *et al*., 2018; Zahn *et al*., 2020). Further, the study implements Malawi 2063 plans and efforts by the Government of Malawi aimed at promoting the large-scale use of clean, efficient and sustainable energy such as ethanol. The fuel/stove adoption and use would help reduce non-sustainable forest resource extraction and lessen the emission of pollutants (BCB International, 2015). Once large-scale users adopt the technology, in the long run, there would be less pressure on forest and energy resources, hence resolving issues of climate change. The research has significantly helped to understand technical, social-cultural and economic aspects that would affect large scale adoption and continued use of ethanol briquettes. The findings, therefore, form a guiding tool for making informed decisions in the energy sector.

1.8 Chapter summary

This chapter has introduced the study by giving background information. It further has emphasized the research problem and why it should be addressed to know the factors that affect large scale adoption of ethanol briquettes in Malawi. The chapter has also outlined the objectives of the study, research questions and hypotheses. It has illustrated the significance of the study and its contribution to sustainable development goals, and the Malawi 2063.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter overview

This chapter reviews literature relevant to this study. It provides a fundamental understanding of the variables that are used in the study. An overview of existing cooking fuels and stoves in Malawi, studies on ethanol as an alternative fuel for cooking, theories guiding the uptake of cooking fuel and stoves are looked at as independent variables while ethanol briquettes and stove uptake/adoption is the dependent variable.

2.2 Review of existing cooking fuels in Malawi

Charcoal is one of the primary sources of biomass cooking energy in Malawi (Kambewa & Chiwaula, 2010). It is still growing in popularity and is regularly purchased especially due to its high demand for cooking. Most urban dwellers rely on charcoal for cooking and the demand remains to be high. The most common stove used for burning charcoal is the Kenya Ceramic stove also known as the improved Jiko (UNDP, 2007). In rural areas, the use of charcoal for cooking is generally low and most of the produced charcoal is sold in urban areas and the majority of households use firewood. Kambewa and Chiwaula (2010) found out that firewood is commonly used in rural areas because households can collect it free from various sources than in urban areas. The purchase of firewood is a common practice in urban areas than free gathering. In general, households in Malawi use about 76 percent of firewood for cooking, 21.5 percent for heating water, 2 percent for space heating and the remainder for other uses (Gamula *et al.*, 2013). The most common devices that use firewood are a 3-stone stove, an improved portable stove such as Chitetezo Mbaula and fixed clay stove such as the Changu-Changu Moto and Total Land Care Rocket stoves.

Electricity is one of the sources of clean cooking energy alternative available in Malawi. Approximately 11.5 percent of people living in all the urban areas in Malawi use hydroelectricity which is distributed by the Electricity Supply Corporation of Malawi (ESCOM) for domestic use. However, the percentage of those using electricity for cooking is much lower. Other sources of electricity include solar, petrol/diesel generators but they are rarely used for household cooking. Electricity is a modern and clean cooking energy solution but it is not used exclusively due to frequent outages, lack of affordability and accessibility by many. In both rural and urban areas, households still use biomass fuels from crop residuals or wastes such as maize bran, and stalks which are sometimes pressed to produce briquettes (Faxälv, 2007). Moreover, a study by Winrock International (2017) found out that the use of clean cooking fuel such as electricity ethanol, biogas, liquefied petroleum gas and solar is low in some parts of the world like Malawi. Instead, these fuels are mostly substituted with charcoal, firewood and electricity (Choumert *et al.*, 2017).

2.3 Studies on ethanol as alternative cooking fuel

Ethanol is largely produced in Malawi but the product is mainly used for petrol blending (Gamula *et al.*, 2013). Among others, ethanol is used as a sanitiser and for medicinal use and not often as a cooking fuel (Stockes *et al.*, 2010). The government of Malawi through the Ministry of Energy established the Promotion of Alternative Energy Sources Programme (PAESP) in the year 2006 to promote the use of alternative sources of energy, and ethanol was identified as one of the best substitutes for charcoal and fuelwood

(Faxälv, 2007). Stockes *et al* (2010) observe that the Ethanol Company of Malawi and Press Cane Limited produce and supply more than 18 million litres of ethanol annually. Furthermore, Stockes *et al* (2010) and a report by UNDP (2007) observe that the capacity of ethanol produced in Malawi is adequate to meet the household energy needs if it is used as an alternative fuel for cooking.

In South Africa, Lloyd and Visagie (2007) found that the performance of ethanol gel fuels is poor when compared with alternative cooking fuels. In this vein, Lloyd (2014) conducted a pilot test that showed that ethanol gel was able to replace paraffin as a dominant cooking fuel in a low -income urban areas in the country. It was noted that the fuel operates efficiently, burns cleanly and spills less because of the gel form. However, the study suggested improvements on the stove to make it more reliable and long-lasting with fewer production costs. In Malawi, a pilot study on bio-ethanol as a household cooking fuel using super blustove in peri-urban areas was found to be theoretically suitable for use but suffered challenges (Robinson, 2006). Ethanol's low viscosity and surface tension make it flow freely thereby causing skin burns amongst users. Besides, the ethanol smell and smoke during combustion from the cookstove caused eye irritation. However, Robinson (2006) suggested that further work should be done to improve the safety and performance of the stove, fuel usage as well as to reduce emissions.

Since ethanol easily spills during cooking, studies have been conducted to produce a safer fuel for use by households. Emoleila *et al* (2016) argues that ethanol could be made viscous by adding thickening agents such as cellulose and water. Their results showed that after denaturing and adding thickening agents the fuel burned cleanly but slowly with the high heat output and they observed that the high viscosity reduced with an increase in temperature (Emoleila *et al*., 2016).

A study by the United Nations Development Program (UNDP) on the evaluation of the Ethanol experience in Malawi indicated that the fuel has the potential of substituting traditional fuels such as charcoal and fuelwood because ethanol is harmless and convenient when cooking (UNDP, 2007). The study also discovered that cooking using ethanol gel had low indoor emissions, Particulate Matter (PM) and Carbon Monoxide (CO) compared to the other fuels and stoves. A study by Oketch (2013) agreed with a report by the UNDP (2007) on the viability of ethanol for cooking but he emphasized the need for optimization of the performance of ethanol cookstoves. The study argues that emissions can be greatly reduced if both parameters of the cookstoves for low emission and high stove performance are optimized to intensify combustion and heat transfer of ethanol gel fuel. The results of the study indicate an improvement of combustion performance of the cookstove, full utilization of ethanol gel with maximum thermal energy and reduced gaseous emissions.

Advanced stoves and clean fuels such as solidified ethanol fuel (BCB International, 2015) has not only shown the utmost potential for achieving the health and safety of users but also keeping a green environment. Zuzarte (2007) studied the feasibility of small-scale ethanol supply and its demand as a cooking fuel in Tanzania. The research revealed the need to determine whether a household will adopt, use and maintain over time a cleaner-burning technology. The study also found that consumer choice of fuel selection depends mostly on the social factors and the economics of the households.

In Malawi, a study was conducted to compare the cost of cooking in terms of useful energy estimated based on the performances of various stoves when cooking (Robinson, 2006). Ethanol stoves (Bluwave, Clean Cook and D&S gel fuel), improved charcoal stove (Jiko) and improved wood stove (Chitetezo Mbaula) were used. The results of the study showed that one litre of ethanol paired with Clean Cookstove displaces 5kg of wood and 2kg of charcoal.

2.4 Understanding the process in the adoption of alternative energy

The adoption of alternative cooking energy is a process that consists of three main stages (Winrock International, 2017). The first stage is the uptake/purchase of both stove and fuel. The second stage is the initial use, and the last phase is sustained use which involves consistent use, repair and replacement of the stove. Adoption is a complex phenomenon but it is sometimes equated only with acceptance and initial use, but sustained adoption (e.g., long-term, consistent use) is critical to achieving greater impact (Orr *et al*., 2014). The factors that influence each stage of adoption varies, but centre around ease of access; perceived risk; affordability and financial constraints; stove performance; and consumer expectation. In Malawi, adoption remains limited, and most urban and rural households continue to use the traditional three-stone fire and charcoal (Orr *et al.*, 2014).

2.5 Theoretical studies on the adoption of alternative energy

The study reflected on theories resting on variables such as the social-cultural, economic technical and policy influences. Fuel switching is when a household ceases to use a customary fuel and adopts another fuel type as a replacement (Choumert *et al.*, 2017). There are misunderstandings between fuel switching or transition and fuel stacking behaviours of households (Tembo & Sitko, 2015). There are a lot of models of guiding energy switching from elementary or traditional (charcoal and firewood among others) to modern fuels such as ethanol. The theories below help in understanding the arguments by different authors on successful switching and adoption of modern cooking energy fuels and stoves and also state the theoretical framework of this study.

2.5.1 Energy ladder theory

Energy ladder theory emerged in the 1970s and 1980s to respond to the global fuelwood crisis (Kowsari & Zerriffi, 2011; Toole, 2015). The model became famous when Hosier and Dowd (1987) published a paper to discuss the cooking energy transition. The model's foundation is on consumer economic to energy with assumptions that households act as utility-maximizing neoclassical (Toole, 2015; van der Kroon, 2016). The choice of energy should be understood based on the economic situation of a household (van der Kroon *et al.*, 2011). When the income of a household increases, the uptake of modern fuels also increases. Households are likely to choose and finally adopt modern fuels that are clean, efficient and easy to use when they have an adequate and stable income. The energy ladder theory argues that households switch to modern fuels up the energy ladder when their income status is high, but Masera, Saatkamp and Kammen (2000) argues that apart from the high-income status of households, there are several things to consider such as availability of fuel and cooking devices, and accessibility at reasonable costs. It is important to understand that the choices of consumers are rational and they would choose to move up the ladder as soon as they are capable of doing so (Kowsari & Zerriffi, 2011).

In the energy ladder theory, the use of modern technology follows a linear relationship with the income of households but Masera *et al* (2000) have found out inconsistent results that prove that the theory is very limited in reality. Heltberg (2005) discussed that when consumers make a move to use new fuels, it means that they have moved away from the old fuels for good but that is not the case in reality as people sometimes use their fuels for different purposes.

The energy ladder has an order of cooking fuels according to preferences of consumers based on cleanliness, ease to use, speed of cooking and fuel efficiency (Hiemstra-van der Horst & Hovorka, 2008; van der Kroon, 2016). The fuels in the ladder were categorised into primitive, transitional and advanced (van der Kroon *et al.*, 2011). At first, down the ladder, families with adequate income abandon traditional (old, less costly, unclean) fuels, and choose to move using fewer pollution fuels up the ladder. Families with high-income levels and status use more efficient although costly, easy and less polluting fuels (van der Kroon, 2016). According to Masera *et al* (2000), households that are wealthy use cooking fuels in the final phase (electricity, ethanol, gas etc.) while the poor use those in the initial phase (wood, dung, etc).

2.5.2 Energy leapfrogging theory

Although leapfrogging does not constitute a theory in itself, several authors such as Batinge, Musango and Brent (2017) and Blimpo, Minges and Kouame (2017) have used it to understand the transition from traditional to modern, clean and sustainable alternative energy technologies. Energy leapfrogging theory advocate that modern technologies that rich countries and households use should trickle down to poor countries and households who cannot create cooking solutions (Atanassov, 2010). Despite having abundant resources, poor countries have an insufficient capacity as they continue facing technical and financial challenges to make new cooking fuels/stoves that are efficient (Murphy, 2001).

The theory urges developing nations to adopt modern cooking services that are used in rich nations to lessen the environmental problems that might be caused by the persistent use of unclean energy such as fuelwoods (Batchelor *et al.*, 2019). Once modern technologies have been developed abroad, developing countries should promote them through price subsidies, and policies that aim at facilitating quicker adoption to households that cannot afford them (Atanassov, 2010). According to Murphy (2001), the approach in this theory is top-down. In some parts of Africa like South Africa (Batinge *et al.*, 2017), modern energy systems have expanded because they inherited through leapfrogging towards technologies from industrialized regions around the world (Riahi, McCollum & Krey, 2012). The energy systems have improved much more rapidly and dramatically through the leapfrog technique (Riahi *et al.*, 2012). Following the energy leapfrogging, Tukker (2005) contends that developing nations like Malawi and poor households should leapfrog into sustainable energy systems. This could be achieved by learning and adopting the most recent technologies in a fast and cost-effective or cheap way to move away from traditional fuels (Riahi *et al.*, 2012). It has been noted some cooking technologies such as stoves and fuels from rich nations mostly fall short of meeting conditions existing in local scenes making it a barrier to adoption and continued use (Murphy, 2001).

A study by Blimpo *et al* (2017) has revealed that although Africa is not new to leapfrogging, there must be proper top-down approaches to trickle down the technologies as well as bottom-up approaches that should aim to meet local needs and challenges. Since not all leapfrogging attempts are successful in Africa, studies (Batinge *et al.*, 2017; Tukker, 2005) have suggested that the barrier to adoption could be alleviated if leapfrogging focus on moving towards sustainable technologies without entirely copying western innovations. This study suggests that modern technologies should be modified to easily meet the cultural, social, and economic aspects of local communities for easy adoption.

2.5.3 Energy stacking or energy mix theory

Energy stacking is the practice of using multiple or more than one fuel type to satisfy daily cooking needs. Energy stacking which is also called energy mix is a revised theory that emerged after criticisms of the latter energy ladder philosophy (Rogers, 2020). This theory suggests that households use several forms of energy or cooking fuel, consuming a higher proportion of superior fuels with rising income (Toole, 2015). In general terms, wood fuel is rarely and completely replaced, even with the availability of modern alternative fuels. Evidence from a growing number of countries suggests that the adoption of alternative energy often results in multiple fuel use, where households consume a portfolio of energy sources at different points of the energy ladder (Odoi-Agyarko, 2009).

2.6 Consumer behaviour on the choice of cooking energy

It is important to understand that households have different choices of cooking energy for their daily use. Consumers behaviour always influence the adoption of cooking fuels since they always make decisions on what fuel to use and how often to use it, when and with what dishes among several other options (Toole, 2015). In some circumstances, consumer behaviour is determined by their choices to meet their needs depending on their financial ability to use a particular fuel or modern cooking services (Rahmani *et al.*, 2020). A study by Atanassov (2010) revealed that most households choose cooking energy depending on several factors. The diverse lifestyles, fuel purchasing patterns, family size, taste preferences, education level and income level of households may influence decisions of adopting and using modern cooking energy (Pope *et al*., 2018). The CI-Change model that focuses on the behaviour of consumers (Kar & Zerriffi, 2018) has been developed, but our study would not discuss it in detail.

2.7 Empirical surveys of consumers behaviour on the choice of cooking energy

In this study, several previous empirical studies that were conducted by researchers worldwide are reviewed to understand the behaviour of consumers on either fuel/stove switching or stacking. Empirical studies of households' behaviour on fuel and or stove choice, adoption and continued usage have been conducted by many researchers around the world. Most of the studies have testified energy stacking is the main fuel adoption behaviour by households. Some of the examples that support stacking behaviour are as discussed:

In Nigeria, specifically Bauchi Metropolis, there is a high frequency of energy stacking behaviour where households who are in the category of middle and upper-income levels adopted more than one fuel type for cooking (Ado & Babayo, 2016). Mekonnen and Köhlin (2008) also studied the fuel choice behaviour of households in Ethiopia. Their results confirmed the existence of multiple fuels choice among households in major Ethiopian cities. Hosier and Dowd (1987) examined households' fuels choice in Zimbabwe using the multinomial logit model. Mensah and Adu (2013) discussed that though the findings of Hosier and Dowd confirm the energy ladder hypothesis, there are other factors such as size and location of households that influence the choice of cooking fuel to use. Big families prefer cooking using charcoal or firewood especially when located in remote areas where other fuel alternatives are not available in the fuel's choice decisions of households.

2.8 Factors influencing adoption and continued use of alternative energy fuels

Several aspects should be considered when new fuels are introduced and promoted in Malawi and elsewhere for successful adoption and use by households. The promotion the modern energy cooking services should rather be inclusive than exclusive by assessing the needs or preferences towards cooking fuels (Seguin & Jagger, 2018). As quoted from previous studies (Budds & Rouse, 2001) “many initiatives have been designed according to the priorities of the implementers, or assumed priorities of the intended beneficiaries, with little perception from users. As with other development projects, many initiatives have failed through failing to meet user’s needs, which include both practical and socio-cultural factors”. In this study, the review has focused on technical, social-cultural and economic factors to understand the reasons that might barrier households from choosing to adopt modern fuels such as ethanol.

2.8.1 Technical factors

The performance of new technologies must satisfy the users’ needs if they are to be adopted and used continuously. Poor quality stoves and fuels are likely to be unaccepted by households. Low-quality cookstoves may cause negative expectations for the improved cooking technologies, leading to lower adoption rates (Hof, Lucas & van Vuuren, 2019).

2.8.2 Social-cultural factors

There are many social-cultural issues associated with household choices to adopt and use clean and modern fuels. These are the traditions, social norms, customary practices and socially developed preferences like taste preferences, cooking practices, local cuisine, kitchen type, gender relations and cultural attachments; which may influence choice of fuel used (Atanassov, 2010). Stove adoption and use are dependent on many other factors including climate, cultural norms, and specific cooking fuels and food preferences (Bailis et al. 2007). Concern Universal commissioned a study to assess the social-cultural acceptability of improved cookstoves (Concern Universal, 2011). The findings of the study revealed that some households in Malawi have perceptions that traditional cooking solutions such as firewood and charcoal cook food faster, and are culturally appropriate (Concern Universal, 2011). This perception decreases the adoption and exclusive use of new technologies, hence a need to be checked.

Where traditional cooking fuels such as firewood are collected freely and not purchased, the time adoption and exclusive use of modern fuels and improved cookstoves are always longer (Nerini & Boulkaid, 2017). However, health gains that could be realized after the use of a modern fuel could also influence adoption and continued use. Stoves and fuels that produce little or no greenhouse gases are likely to be adopted by households. According to a feasibility study on the use of ethanol for cooking in Malawi, UNDP (2007) reported that the choice of consumers to use the fuel was influenced by both its speed and convenience of cooking, cleanness, and safety. The study revealed that ethanol in liquid form is dangerous, hence pose risks to users.

2.8.3 Economic factors

In a recent study by Esong *et al* (2021) they pointed out that the initial costs of prices of cooking fuels, socioeconomic status, household wealth, were listed as some of the determinants of modern fuels adoption in households. The initial costs of purchasing a stove and inserts can be a barrier to the adoption of improved and clean cooking solutions (Nerini *et al.,* 2017). There is a need to encourage adoption by households through various options to own a stove either by subsidies or free allocation (Malla & Timilsina, 2014). In Kenya, it was noted that cooking appliances for ethanol were costing high thereby creating a hindrance in the adoption of both the fuel and the stoves. KOKO Networks and other companies made available stoves of different ranges, priced them depending on their brand, and promoted them so that users have a wide choice depending on their income (CCAK, 2019; Ngeno et al., 2018).

According to the Guatemala Eastern Reserch Group [ERG] (2016), the cost of fuel to the user is an important aspect that influences adoption. Fuels that are highly-priced are mostly likely to stay longer on the market and remain unpurchased (ERG, 2016). According to Puzzolo *et al* (2013), effective pricing would be one of the key aspects of increasing adoption of new fuels and stoves, and move away rapidly from traditional biomass cooking fuels and devices. Puzzolo *et al* (2013) argue that taxation added on ethanol fuel substantially increase ethanol price and limit the number of households able to pay for the fuel. The study suggests that a separate taxation system should be put in place to favour the adoption of ethanol.

2.9 Chapter summary

This chapter has clearly shown the knowledge gaps the study attempts to fill. Literature on the processes and theories regarding adoption and sustained use of clean alternative energy solution have been clearly discussed. The chapter has also reviewed several factors that influence the choice of households to adopt and use clean cooking energy. Since adoption is dependent on many factors the study reviews social, cultural, economic and technical aspects.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Chapter overview

This chapter is about the methodology that was employed to undertake this research study. The chapter is divided into the following sections: conceptual framework, study setting, research design, data collection methods, data analysis and research ethics.

3.2 Conceptual framework

The conceptual framework presents the research argumentation, explanation, and generation (Crawford, 2020). The study has been undertaken based on logical reasoning that technical, social-cultural and economic factors associated with household cooking fuel and stoves could be used to assess their impacts on the adoption and use of ethanol briquettes. This assertion required testing and well explanations to achieve the research objectives.

A pilot study on the existing cooking fuels was done to establish the gap that the research has addressed. The study design implored the use of experimental/analytical, qualitative and quantitative techniques to aid the evaluation of technical, social-cultural and economic aspects. The approach provided rigorous outcomes to the study parameters.

Technical indicators including dimensions of combustion chambers were prototyped, measured and tested following Water Boiling Tests (WBT) protocols and standards.

Ethanol briquettes and charcoal fuels were used with either Kenya Ceramic Jiko or Chitetezo Mbaula stoves. Performance and efficiency indicators such as time to boil, fuel consumption, thermal efficiency, firepower and flame distribution were analysed. A bomb calorimeter and oven were used to determine the energy and moisture contents of the fuels respectively. The indoor air pollutants such as carbon monoxide and particulate matter were analysed from the samples. The results were compared with the World Health Organisation (WHO) standards (WHO, 2020). Controlled Cooking Tests (CCTs) were conducted to determine the results on time to cook a specific quantity of dish/meal; fuel consumption for a specified cooking task; and total cooking time from starting the fire to when the food was considered cooked. The amount of used fuel; and the ease of cooking with ethanol briquettes were measured and observed respectively.

Social-cultural indicators were also analysed to find out the likelihood of the improved stoves paired with ethanol briquettes for possible adoption. Finally, economic indicators such as the economic status of households, and the cost of fuel were analysed. The parameters that were kept constant include types of stove and combustion containers for the Chitetezo Mbaula and Kenyan Ceramic Jikos, type of cooking pots, quantities of water for WBT and foodstuffs for CCT. The tests were done following the International Organisation for Standardization (ISO) version 4.2.3 and the International Workshop Agreement (IWA) guidelines for evaluating cookstove performance (WBT Technical Committee, 2013). The scope of the study in Figure 3.1 shows the parameters and the extent to which the research was conducted.

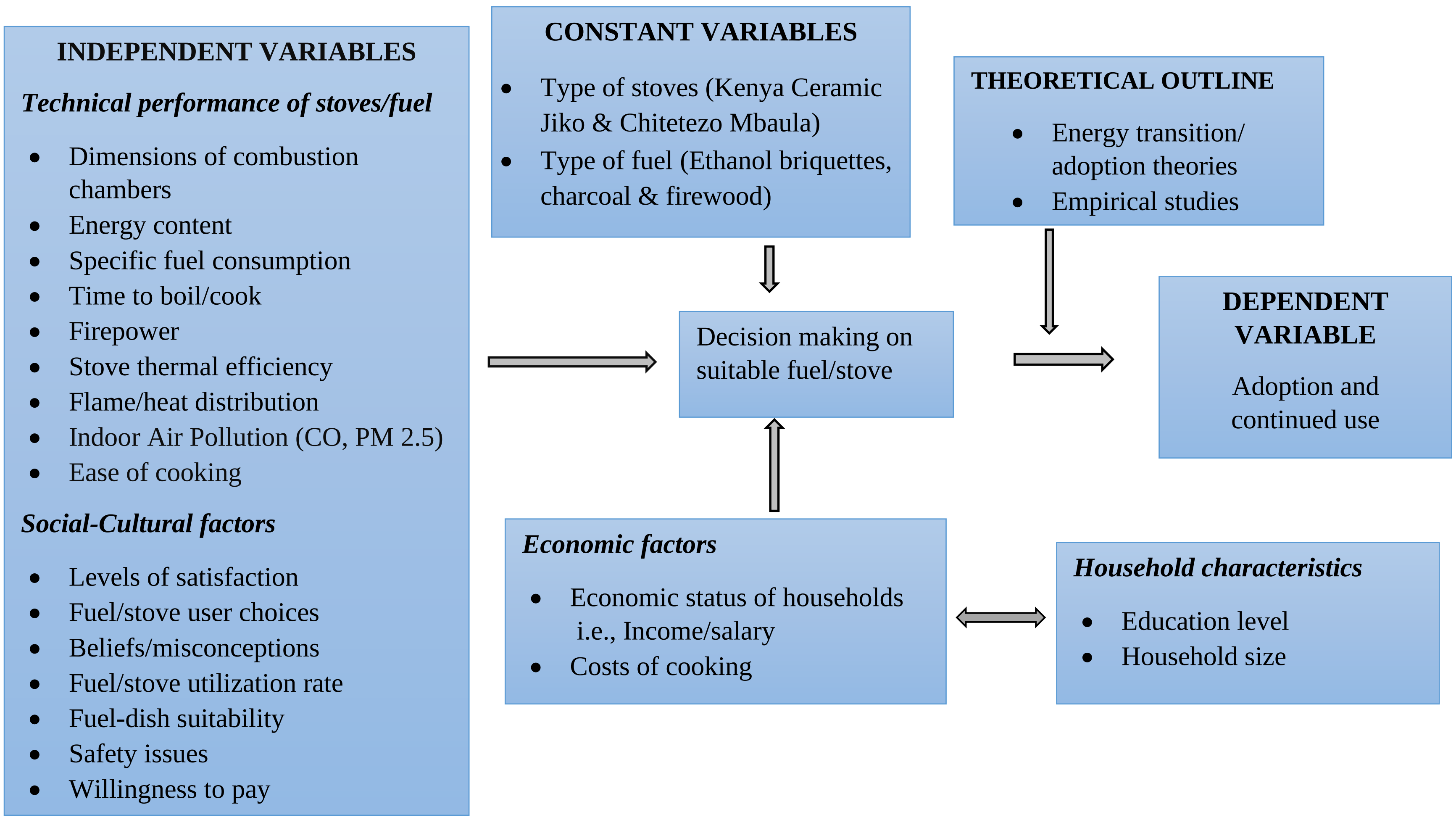


Figure 3. 1 Scope of the Study Source: Author, 2022

3.3 Geographical sites where the study was conducted

The study was conducted in residential Areas 36, 44 and 49 in Lilongwe, the Capital City of Malawi. In order to best evaluate the adoption and sustained use of ethanol briquettes I required study areas that have a population with high dependance on charcoal or fuelwood for cooking. As showed in Figure 3.2 the areas were selected because they are strategically located closer to charcoal and firewood main markets, and the households have different social economic characteristics and sources of cooking energy.

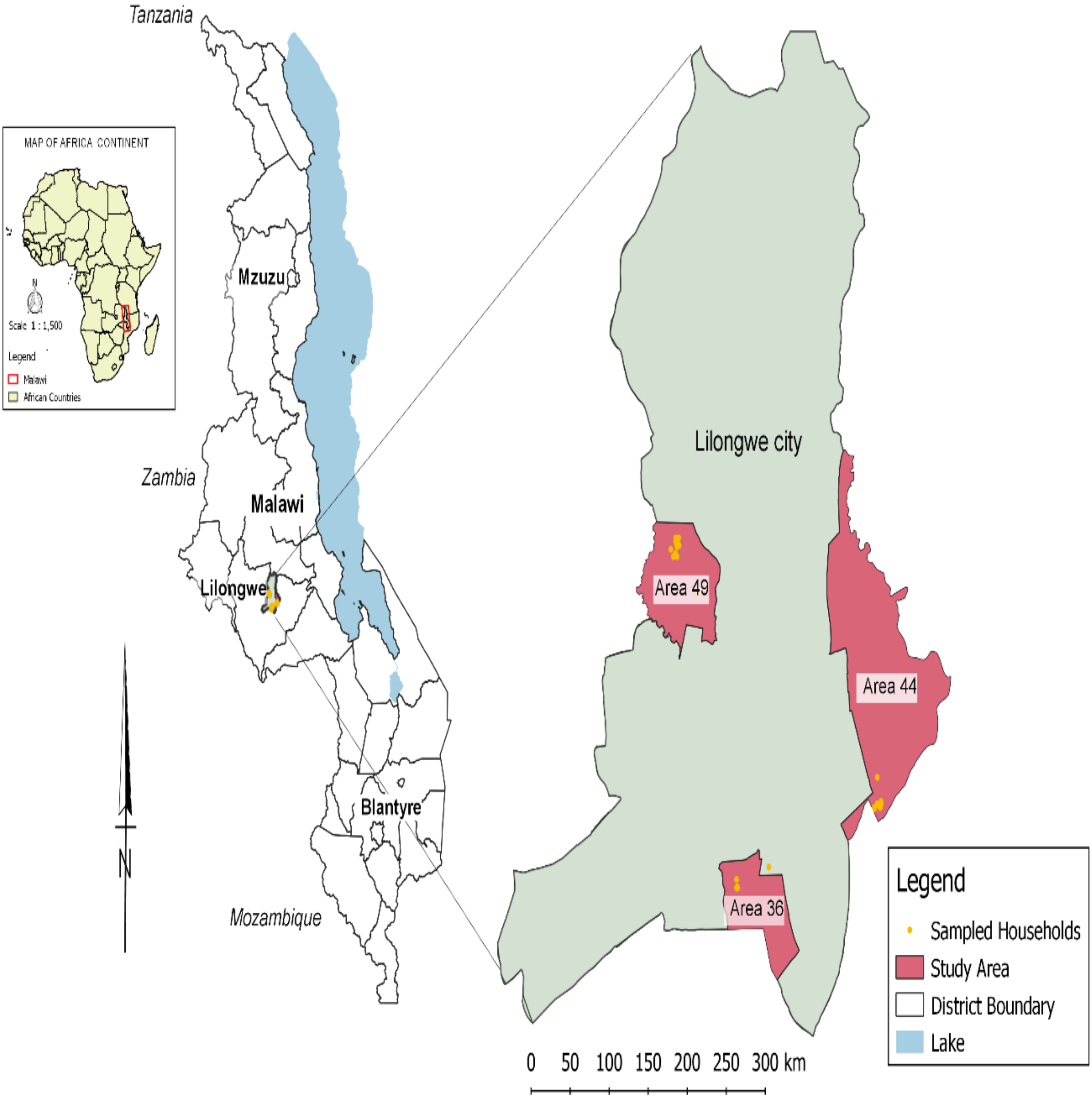


Figure 3.2 Map showing the study locations in Lilongwe city

Source: Author, 2022

3.4 Sampling strategy and sample size

The research used the purposive sampling technique to select residential areas 36, 44, and 49. In each stage, a criterion of sampling is based on the reliance on biomass energy for cooking. Table 3.1 show a sample size of 53 households that were involved in the study. The households were chosen using a systematic sampling method. The participants were verified based on being users of either charcoal or firewood as the main fuel for cooking.

Table 3. 1: Sampled households in the study areas.

Location	Number of Households
Area 36	9
Area 44	15
Area 49	29
Total for all Areas	53

Source: Author, 2022

3.5 Research design

A pilot study on the existing cooking fuels and devices was conducted to establish the research gap before the implementation of ethanol briquettes and cookstoves. To understand the viability of ethanol briquettes as a suitable household cooking fuel alternative, all the 53 households were given exactly 1.7 Kg of each fuel (ethanol, wood and charcoal) each week, for three weeks. The households were given the chance to choose the stoves and fuels which they would want to use for a particular cooking task. The participants were first informed of the project and made fully aware of the arrangement, commitments, safety and privacy issues before being asked to sign a consent form. Each household was visited four times. Chitetezo Mbaula and Kenyan Ceramic Jiko stoves were distributed to the households and later they swapped to ensure that every participant used the two cookstoves.

Four focus groups were conducted in two stages: First, in the middle of the cooking exercise before swapping the stoves, and last was done on the twenty-first day which was the final day of ethanol briquettes implementation by the households. The focus group discussions solicited the ideas and opinions of the participants regarding the performance of ethanol briquettes and cookstoves. The economic and social-cultural factors that influence the choice of uptake/adoption were also discussed. Finally, a household survey was undertaken to collect quantitative data that later formed a basis of comparisons between ethanol briquettes and charcoal.

3.6 Data collection methods

The primary data for the study were collected using both laboratory and field experiments, household surveys, cooking diaries, focus group discussions, and charcoal market assessments. The study also relied on secondary data sourced from existing literature in journals and books. The data collection methods are discussed in the following sub-sections.

3.6.1 Household surveys

The baseline and end-line household surveys were conducted to collect basic household information (GPS, household size, demographics, income levels, etc) and cooking practices (expenditures, devices used, frequency etc) before the distribution of the ethanol briquettes fuel and after the completion of the study. Structured and semi-structured questions were translated to the Chichewa language for easy of communication with the participants. Further, the questions were coded and implemented electronically using Kobo collect software. The surveys were implemented by a team of trained enumerators after pre-testing and training.

3.6.2 Cooking diaries

Cooking diaries are data collection forms that are filled out by the participant each time they used a cooking appliance for cooking or heating (Leary, 2018). The participants were trained on how to record the cooking start and end times, food/dish cooked and devices used for every meal (Batchelor *et al.,* 2019). Printed cooking diaries (Figure 3.3) were issued to each participant to record up to four dishes/food for each meal. Each participant recorded data for three weeks.

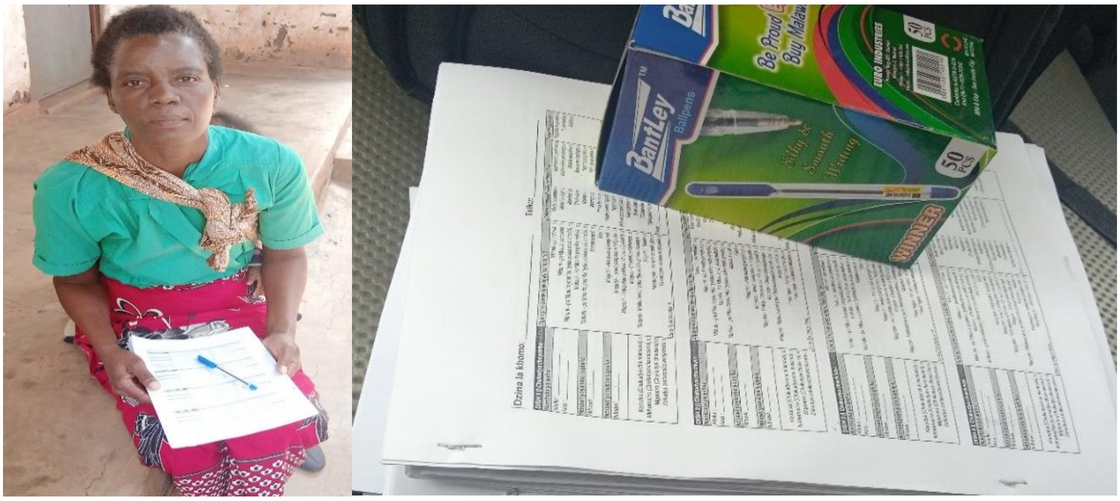


Figure 3.3 Cooking diaries data collection booklet received by a study participant.

Source: Author, 2022

3.6.3 Focus group discussions

Four focus group discussions were conducted to assess the views and perceptions or observations of participants. The discussions focused on the choices of consumers, willingness to pay, and influences of cultures and cooking behaviours on fuel adoption. Figures 3.4 and 3.5 show focus groups categorised as group A and group B, and the discussions took place in Areas 44 and 49 respectively. Each group was engaged two times to gather information before and after the implementation of ethanol briquettes.

Figure 3.4 Showing participants for Group A

Source: Author, 2022

Figure 3.5 Showing participants for Group B

Source: Author, 2022

3.6.4 Charcoal market assessments

Charcoal market assessments surveys were conducted in the main markets of Area 49 (Mtandire market), Area 36 (Wakawaka market) and Area 44 (Chimutu Market). The questionnaire is shown in Appendix 3. The markets were purposively selected, where a total of 15 charcoal vendors comprising of 3 large scale vendors from each main market and 2 small scale vendors from areas close were identified through the market chairpersons/leaders. The vendors were interviewed using a semi-structured questionnaire and the charcoal bags were weighed using a scale to measure quantities of usable charcoal.

3.7 Design, construction and experimentation

Field experiments focused on the design, prototype and test of combustion chambers that were used to burn ethanol briquettes fuel. Highly controlled laboratory experiments were conducted using procedures of bomb calorimetry for calorific value measurement (Shizas & Bagley, 2004), protocols of water boiling test version 4.2.3 (WBT Technical Committee, 2013), controlled cooking tests (Bailis, 2004), and emissions (Defoort *et al*., 2009). These protocols and procedures were used to determine the stove and fuel efficiency, emissions and performance.

3.7.1 Prototyping stoves and combustion chambers

Chitetezo Mbaula and Kenya Ceramic Jiko were purchased from a stove manufacturer in Lilongwe District, Malawi. A local tinsmith was engaged to archetype metallic combustion chambers for burning ethanol briquettes. Each container design has no cover on top for easy refilling of fuel and to allow flame/heat to flow upwards once ignited (Figure 3.6). The area, circumference and volume were calculated using equations [3.1] through to [3.4] as described by Berko (2018). The area (A_c) and circumference (C_c) of the combustion chamber aperture are given as:

$$(A_c) = \pi r_c^2 \qquad [3.1]$$

$$(C_c) = 2 \pi r_c \qquad [3.2]$$

where r_c = radius of the combustion chamber in cm. The volume of the combustion chamber is given by:

$$\text{Volume} = \pi r_c^2 \times \text{h} \qquad [3.3]$$

where h is the height of the combustion chamber in cm.

Holes of 5 mm diameter were drilled on the side surfaces of the combustion chamber at an interval of 1.30 cm to enable maximum air circulation. Using the designs shown in Figure 3.6, combustion chambers with different dimensions were prototyped and later on tested along with ethanol briquettes of equal block weight (27g) using procedures provided by the Water boiling test protocol 4.2.3 (Maurya *et al.*, 2022; WBT Technical Committee, 2013). A prototype with optimum performance was identified by comparing the WBT results. Finally, the pot bottom and gap from the top edge combustion containers were calculated using equation 3.4 (Berko, 2018):

$$G_C = \frac{A_C}{C_C} \qquad [3.4]$$

where G_c is the gap required, while A_c and C_c are the area and circumference of the combustion chamber in square centimetres respectively.

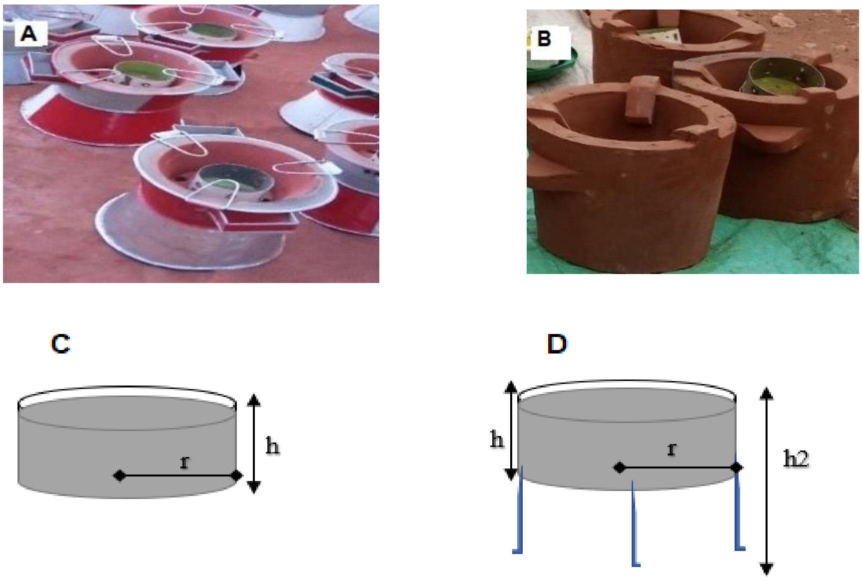


Figure 3. 6: Showing Kenya Ceramic Jiko and Chitetezo Mbaula stoves labelled A and B with their respective container designs labelled C and D

Source: Author, 2022

3.7.2 Ethanol Briquettes tested

The ethanol briquettes were supplied by United Purpose, Malawi and the dimension of each piece was of length 67.5 mm, breadth 40 mm, height 25.6 mm and weight 27 grams (Figure 3.7), for proper fit and burn in the combustion containers.

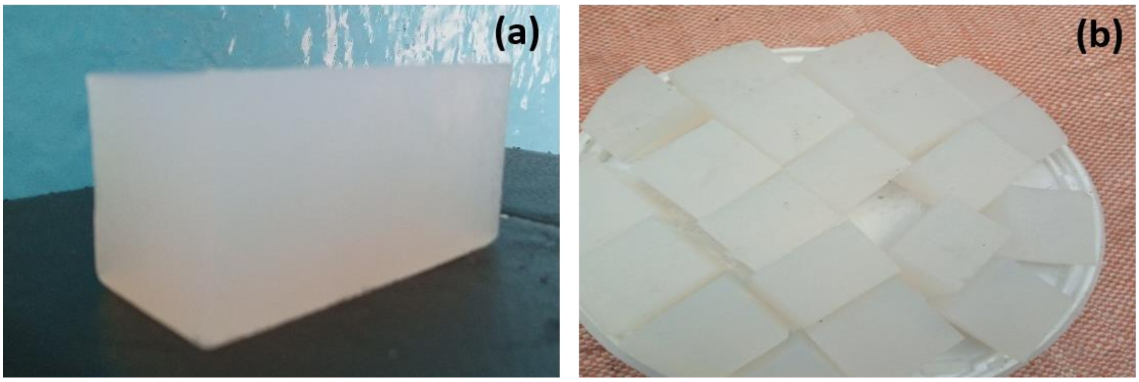


Figure 3.7 (a)- A single block of ethanol briquette (b)- a few blocks of ethanol briquette

Source: Author, 2022

3.7.3 Determination of energy and moisture content

The calorific value of a fuel is essential for determining the efficiency of stoves. An oxygen bomb calorimeter Parr6200 with Parr 6510 water handling system was used in a controlled laboratory setting. With the help of benzoic acid as a standard, the heat capacity of a pelletized sample of ethanol briquettes weighing 0.6±0.01g was combusted in a pressurized oxygen atmosphere to determine the heat capacity following a procedure of bomb calorimetry (Shizas & Bagley, 2004). The same procedure was applied to a dried sample of charcoal. Finally, the average energy content was determined from the values of two samples of each fuel.

The moisture content for both charcoal and ethanol briquettes were determined using the oven-dry method. Water in samples was evaporated at a temperature not more than 100^{o}C until no moisture remained. The samples were measured on a wet basis and calculated using equation [3.5] (Defoort *et al.*, 2009).

$$\mathrm{MC}_{wet} = \frac{Mass_{\,original} - Mass_{dry}}{Mass_{\,original}} \times 100\% \qquad [3.5]$$

3.8 Efficiency and Performance Testing

Apart from the efficiency and performance tests such as time to boil, specific fuel consumption and thermal efficiency, tests to determine stove characteristics including the burning rate and firepower were also conducted. These tests were done following the water boiling test, controlled cooking tests and emissions tests protocols (Bailis, 2004; Defoort *et al.*, 2009; WBT Technical Committee, 2013).

3.8.1 *Water boiling test*

Water boiling points of locations with different altitudes is not the same. The water boiling point was determined by using a method done by Bailis *et al* (2007). A handheld Garmin GPS etrex 20 was used to generate the altitude at University of Malawi laboratory premises in Zomba. To determine the water boiling point, an altitude of 888 ±2 m was measured and used in equation [3.6].

$$\text{Boiling point} = \left(100 - \frac{\mathrm{h}}{300}\right) {}^{\circ}\mathrm{C} \qquad [3.6]$$

where h is the altitude in metres above the mean sea level

The water boiling tests in Figure 3.8 were conducted in a controlled environment to test the stove and fuel efficiency (Ojo *et al*., 2015). The calculated water boiling point of 97.04 degrees Celsius was used. The cold start (high power test) technique was used in this experiment where 1 L of distilled water was measured using a cylinder. An aluminium pot was used to heat the water to reach the boiling point. Two pot treatments: lid off and lid on were compared. The quantity of water remaining after boiling was also recorded.

The experiments were done first by pairing ethanol briquettes with Kenya Ceramic Jiko, followed by Chitetezo Mbaula. Finally, similar tests were conducted using charcoal as a fuel in Kenya Ceramic Jiko and Chitetezo Mbaula stoves and this was carried out to assess the disparities. Indicators such as time to boil and water temperature were recorded using a stopwatch and digital thermocouple sensors (0-100 ^{o}C), respectively. Using a Mettler PM 15 electronic scale, the difference between the initial and the final weight of the cooking fuels were measured. After repeating each experiment three times, a Water Boiling Test protocol 4.2.4 excel sheet was used for calculations of efficiency of the stove (Oketch, 2013).

Figure 3.8 Experimental set-up for water boiling

Source: Author, 2022

3.8.1.1 Time to boil

The time taken to boil a fixed quantity of distilled water weighing 1 litre was recorded using a stopwatch.

3.8.1.2 Specific fuel consumption

Specific Fuel Consumption (SFC) is the ratio of ethanol briquettes or charcoal consumed to boil the fixed measured quantity of water (Boafo-Mensah *et al.*, 2013). SFC for boiling exactly one litre of distilled water is given by equation [3.7].

$$\mathrm{SFC} = \frac{\mathrm{f_{cd}}}{\sum_{\mathrm{j=1}}^{4}\left[(\mathrm{Pj_{ci}} - \mathrm{Pj}) \times \left(\frac{\mathrm{Tj_{cf}} - \mathrm{Tj_{ci}}}{T_b - \mathrm{Tj_{ci}}}\right)\right]} \quad [3.7]$$

where T_b is the local boiling point of water measured in degrees Celsius. Pj_{ci} is the weight of pot with water before the test, Pj is the weight of pot with water after boiling test, Tj_{cf} is the final water temperature, and Tj_{ci} is the temperature of the water before the test.

Following the Water Boiling Test guidelines, any temperature difference before water boiling starts, the Temperature-Corrected Specific Fuel Consumptions (TC-SFC) of charcoal and ethanol briquettes experiments were used to calculate and obtain correct fuel consumption using 75 °C as standard temperature. The following formula was used (Shanono *et al.*, 2020).

$$\mathrm{TC \cdot SFC} = \text{Specific fuel consumed } \times \frac{75}{T_{cf} - T_{ci}} \qquad [3.8]$$

Likewise, Temperature-Corrected Specific Energy Consumptions (TC-SEC) in this study were calculated by multiplying TC-SFC and fuel energy content (Yuntenwi, 2008)

3.8.1.3 Thermal efficiency

Thermal efficiency is a percentage of work done to boil and evaporate water using the energy consumed when burning the fuel. The energy required to boil water at 97.04 °C is obtained using equation [3.9] (Bailis *et al.*, 2007), then divided by a product of LHV and fuel consumed.

$$\mathrm{h_c} = \frac{\left[4.186 \times \sum_{j=1}^{4} (\mathrm{Pj_{ci}} - \mathrm{Pj}) \times (\mathrm{Tj_{cf}} - \mathrm{Tj_{ci}}\right] + 2260 \times \mathrm{W_{CV}}}{\mathrm{f_{cd}} \times \mathrm{LHV}} \qquad [3.9]$$

where Pj_{ci} is the weight of pot with water before the test, Pj is the weight of pot with water after boiling test, Tj_{cf} is the final water temperature, Tj_{ci} is the temperature of the water before the test, 2260 is the latent heat of vaporization, W_{cv} is the mass of water evaporated, f_{cd} is the mass of fuel consumed, LHV is the low heating value of the fuel and j is an index of each pot tested while the subscript -c is for the cold start test.

3.8.1.4 Firepower

Firepower (P) is a ratio of ethanol briquettes or charcoal energy consumed by the stove per unit of time. It is expressed in watts as given by equation [3.10] (Fakinle *et al.*, 2019):

$$P = \frac{\text{Mass of fuel consumed } \times \text{Calorific Value of the fuel}}{\text{Time taken}} \quad [3.10]$$

3.8.1.5 Burning rate

Burning rate is a measure of the rate of fuel consumption while bringing water to boil (Boafo-Mensah *et al.*, 2013). It is calculated using equation [3.11]:

$$\text{Burning rate } = \frac{f_{cd}}{\Delta t_c} \quad [3.11]$$

where f_{cd} is the fuel consumed, and Δt_c is the change in time taken to boil the water.

3.8.1.6 Distribution of flame

The distribution of flame from combustion chambers of stoves to a base of the cooking pot was observed during WBTs experiments. The treatments of stoves were based on settings of no wind, light breeze, moderate wind, strong wind and very strong wind (Oketch *et al.*, 2014).

3.8.2 Controlled cooking test

Controlled cooking tests were done following the CCT version 2.0 protocol (Bailis, 2004). The tests were performed using ethanol briquettes and charcoal to evaluate the fuel consumption, costs and cooking time of the two energy sources (Maurya *et al*., 2022). The tests simulated actual cooking tasks that local people do every day, but the tasks were performed in a controlled environment designed to minimize the factors that might affect the results. Nine people were identified to do the task. Each person was allocated to test all the stoves equally to avoid bias and ensure that they have potential control of the environment and the tools (Faxälv, 2007). To determine the amount of fuel required to cook a meal, the test used three different stove-fuel combinations. A meal containing different foods (nsima, vegetables, and beef) was chosen because it is the common food in Malawi. The quantities of each meal were equal to that of an average household size of 6 people. The weight of food and fuel were recorded before and at the end of cooking. Any ingredients added to the food being cooked are recorded along with the start and finish time of each task.

3.8.2.1 Total cooking time

Total cooking time from starting the fire to ready food

3.8.2.2 Fuel consumption per meal

Charcoal and ethanol briquettes fuel used to cook a meal using the stoves was determined by subtracting the remaining weight of fuel after a cooking task from the initial weight before the task. The specific fuel consumption was calculated using the equation [3.12] (Bailis, 2004).

$$\text{Specific Fuel Consumption } = \frac{F_d}{W_f} \times 1000 \qquad [3.12]$$

where F_d is the fuel used and W_f is the final weight fuel.

3.8.2.3 Total weight of food cooked

The total weight of food cooked was weighed on a digital scale to take final readings.

3.8.3 Indoor air pollution

Pollutants emitted from burning fuels in stoves have detrimental effects on both human being's health and the atmospheric environment. The stove manufacturers Emissions and

Performance Test Protocol (EPTP) were used to determine the emissions (Defoort *et al.*, 2009). Samples of carbon monoxide and particulate matter (PM2.5) were collected using the hood method in the laboratory.

3.8.3.1 Procedure

Background emissions were first collected in the rooms where the experiments were set. Each stove experiment was carried in a separate room so that there is no mixture of gases. The emissions from the stoves were collected using an exhaust hood equipment with the aid of a fan/blower and it was set at a flow rate of 80-150 m^3/hr. A calibrated flow grid instrument was used to measure the flow of emissions. The smoke from the stoves was captured in the hood and flow in the direction of the thick lines and the arrows as shown in Figure 3.9. Samples were collected both downstream of mixing baffles and upstream of the blower (WBT Technical Committee, 2013).

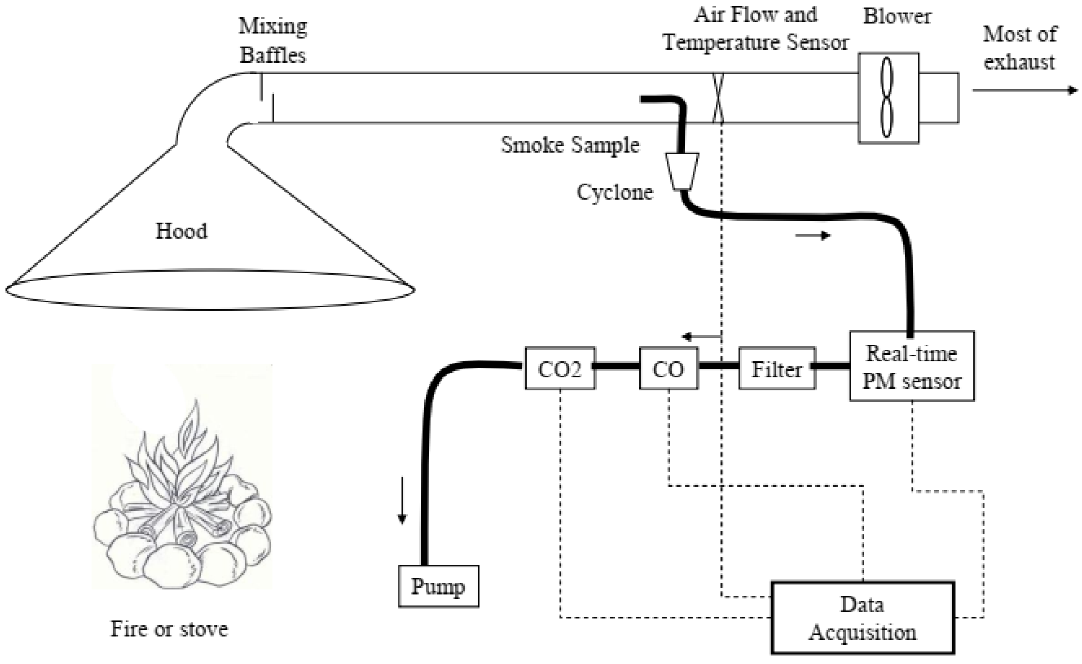


Figure 3.9 An illustration of the hood experiment

Source: Berko, 2018

Suspended particulate matter (PM2.5) were measured using the standardized Indoor Air Pollution (AIP) meter. Real-time Portable Emission Measurement System (PEMS) was used to detect and measure the concentrations of carbon monoxide (Defoort *et al.*, 2009). Data were collected for both ethanol briquettes and charcoal stoves, analyzed and compared to standard values set by the Malawi Bureau of Standards (MBS) and World Health Organization (WHO). The percentage difference between the WHO benchmark and the actual tests were computed in equations [3.13] and 3.14] respectively (Berko, 2018).

$$\text{Particulate Matter} = \frac{\mathrm{PM}_{WHO} - \mathrm{PM}_{TESTED}}{\mathrm{PM}_{WHO}} \times 100 \qquad [3.13]$$

$$\text{Carbon Monoxide} = \frac{\mathrm{CO}_{WHO} - \mathrm{CO}_{TESTED}}{\mathrm{CO}_{WHO}} \times 100 \qquad [3.14]$$

3.9 Ethical Considerations

Ethics inform norms for conduct that distinguish between acceptable and unacceptable behaviour. To comply with University of Malawi research ethics standards, I obtained permission to conduct research in the study Areas from Lilongwe City Council. The households were informed of their right to consent or decline to participate in the study.

3.10 Data management and statistical analysis

Before analysis data were uploaded to a server for storage and safety reasons using the digital mobile platform Kobo collect. Data cleaning was done to ensure that the research findings are of high quality. Both cookstoves and fuels were tested under similar settings to examine the performance. The presentation of data as means and standard deviations were in form of graphs, tables and charts. Statistical analyses such as correlation and multiple regression were done in Statistical Package for the Social Sciences software (SPSS version 22.0). The results and relationships of independent and dependent variables were interpreted at 95% confidence level. The alpha (α) was significant at 0.05. The decision to reject the null hypothesis in favour of the alternative was when the p-value is less than 0.05 and vice versa.

3.11 Chapter summary

This study was multi-disciplinary in nature, involving household information, data that required a quantitative research approach, and interpretation of that data which required a qualitative research approach. As such, a mixed-method approach was most appropriate for this study, for no single approach could have created a meaningful outcome. The methods for data collection were also mixed, and included laboratory tests, field tests and observation, focus group discussions, household interviews, cooking diaries, and market assessments. These produced both qualitative data and qualitative data which were used for analysis. The quantitative approached produced strong and empirical mathematical outcomes. However, descriptive qualitative analysis provided flesh to otherwise meaningless and complex data. Without the merging of the hard natural scientific and soft social sciences approach, it would have been difficult and near impossible to answer the research questions and to achieve the research objectives.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Chapter overview

In this chapter, the findings of the study are presented and discussed in line with the specific objectives of the study. The results are presented first, followed by the discussions.

4.2 Demographics and socio-economic characteristics

Using responses from the baseline survey, some contextualising information is provided to better understand the social, cultural and economic statuses of the households in which the ethanol briquettes fuel was piloted.

4.2.1 Household size

The majority of households in the sample have between 4 and 8 members inclusive (79%) and overall, the households are made up of approximately half adults and half children (52% and 48%, respectively) as shown in Table 4.1. The results revealed that the size of most households is 6 people. This is largely consistent across the three areas.

Table 4. 1: Household characteristics in the study Areas

Area	Sample No. of Households	Number of adults	Number of children	HH size (Median)	Adults (Mean)	Children (Mean)
Area 36	9	30	25	6	3	3
Area 44	15	47	53	6	3	2
Area 49	29	94	78	6.5	3	3
Total	53	171	156	6	3	3

Source: Author, 2022

The number of people in a home may influence the choice of fuel (van der Kroon, 2016). Large the family size requires more food to be cooked hence requiring more fuel.

4.2.2 Education level

Education is considered to be a very important predictor for influencing adoption. In Figure 4.1 about 50.9% attained secondary education while few (3.77%) had tertiary level education qualifications.

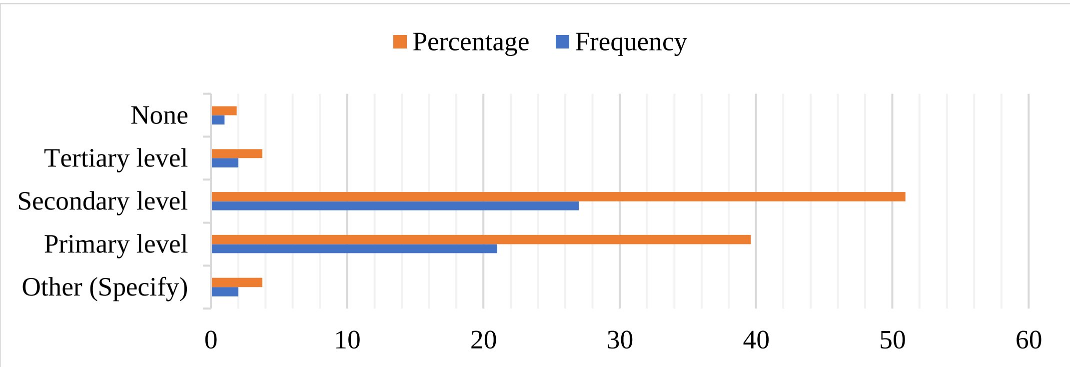


Figure 4.1 Education level of Household heads in the study Areas

Source: Author, 2022

4.2.3 Household incomes and frequency

Most households (Figure 4.2) have income levels between 50,000 and 150,000MWK per month and per capita incomes of between 7,000 and 24,000MWK. The sources of income and their incoming levels are different, though mixed. Overall, the sampled households fall in the category of low-middle income status.

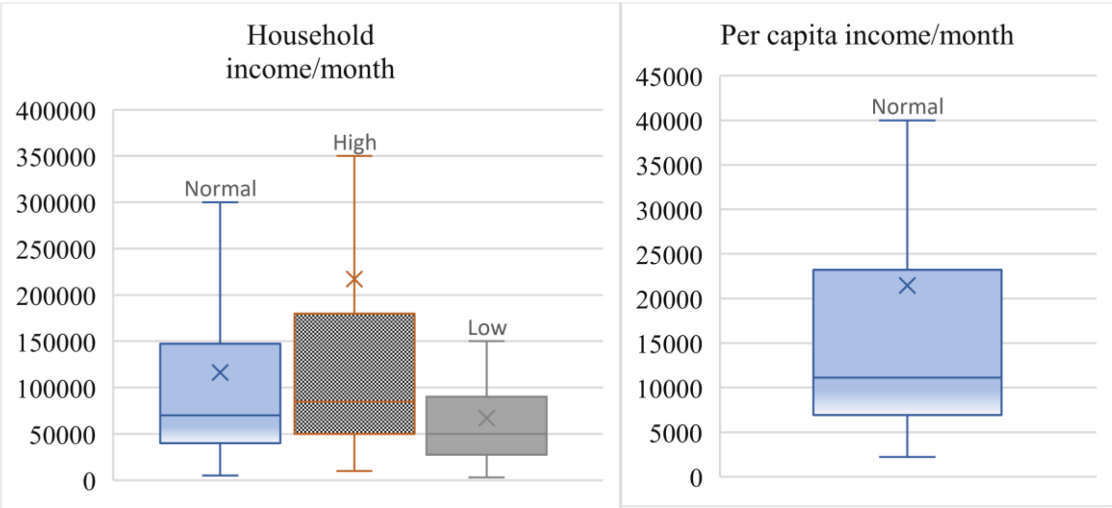


Figure 4.2 Household income levels in the study Areas

Source: Author, 2022

The results in Figure 4.3 show that households receive income at various frequencies. The results show that 34 percent receive daily incomes, 15 percent receive weekly incomes and 30 percent receive monthly incomes while the remainder is spread between these.

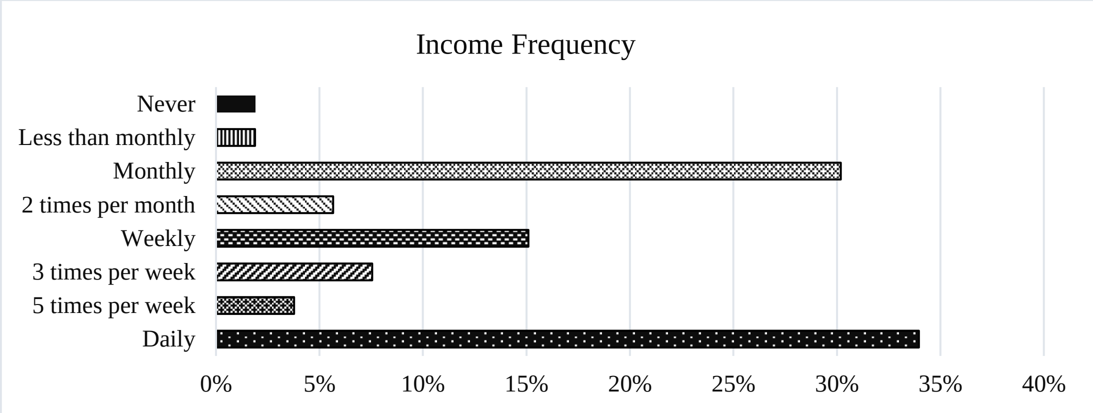


Figure 4.3 Household income frequencies in the study Areas

Source: Author, 2022

The study by Orr *et al* (2014) revealed that biomass fuels were used by the category of wealthiest people but their income influenced them to adopt the modern stoves and stack them with the existing fuels as compared to the poor category. Since the energy ladder emphasises an increase of households' income as a basis that influence the decisions to switch to modern fuels, this study has not found the same. The results on household economic status agree with a study in Nigeria by Ado *et al* (2016) which found that despite high or middle-income levels, households choose to use multiple fuels for cooking as such there is a tendency of stacking traditional fuels such as charcoal and modern fuels such as ethanol briquettes.

4.2.4 Household assets

Table 4.2 show that households owned many assets with over 80% of people owning a phone, bed and table, while more than 50% owned a radio, TV, iron or torch. Ownership of items such as fridge, bicycle, stereo and fixed lighting was lower at around 20-30%. The results show that assets that require different forms of energy are owned and widely used by households. Due to a lack of electricity connection, some assets are not used by the households. This signifies how essential household energy is to humans.

Table 4.2 Household assets

Asset	Percentage	Asset	Percentage
Hairdryer	2	Fixed lighting	34
Car	4	Radio	55
Laptop	8	Iron	60
Fan	13	Torch battery	62
Torch (Rechargeable)	21	TV	62
Fridge	26	Table	83
Bicycle	30	Bed	94
Stereo	32	Mobile	100

Source: Author, 2022

The results in Figure 4.4 show that 98% of the households in all study Areas owned a charcoal stove especially Kenya Ceramic Jiko stove, while 74% owned a 3-stone and Chitetezo Mbaula stove. The results show that 6% of the households owned a Kinda stove. Kinda is an improved cookstove from metal and clay ceramic and it uses sawdust or maize bran briquettes as fuel. Electric cooker/hotplate and Gas cooker counted for 6% and 2% respectively. When households were asked to identify the stove devices they used most often, 87% and 13% selected Kenya Ceramic Jiko which uses charcoal and 3-stone or Chitetezo Mbaula stoves which uses firewood respectively.

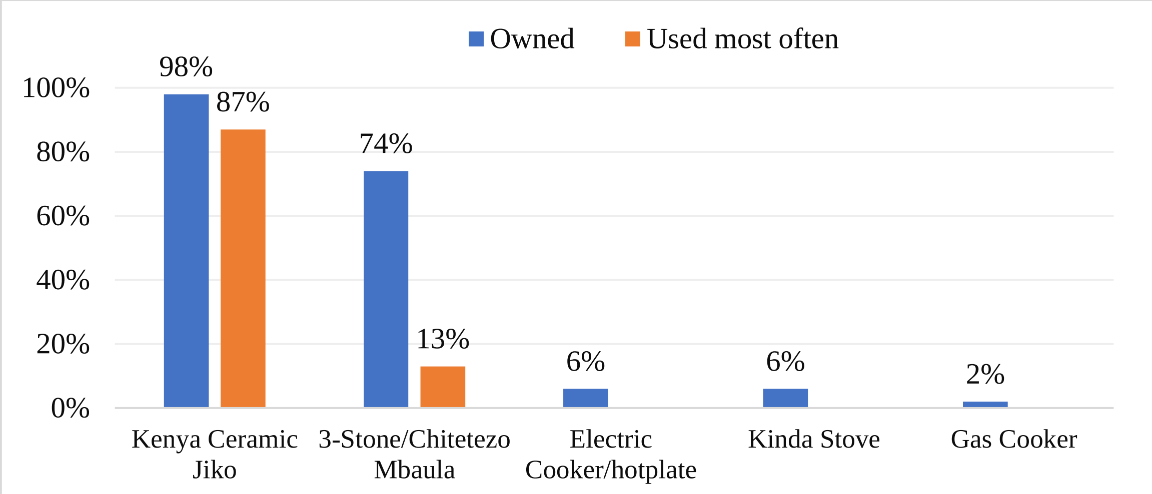


Figure 4.4 Cooking devices owned and frequency of use in all study Areas

Source: Author, 2022

4.2.5 Household cooking aspects

Approximately more than half of the households reported having a kitchen, but the results in Figure 4.5a indicate that generally more than 80% of the households cooked outdoors. However, after the implementation of ethanol briquettes, the results in Figure 4.5b show that 85% started cooking indoors more often than before because the fuel burned cleanly, and efficiently indoors with a minimal breeze. On the other hand, 15% of the study households continued to cook outdoors because they did not have a kitchen or enough space in their main house that could be used for cooking. These results agree with a study in Burkina Faso (Ouedraogo, 2006) which discussed that households who often use traditional and unclean fuels habitually cook outdoors for health reasons as compared to those who use modern and eco-friendly clean fuels as they prefer to cook indoors. The households cook outdoors to reduce indoor air pollution as the fuels often produce a lot of toxic smoke and fly ash.

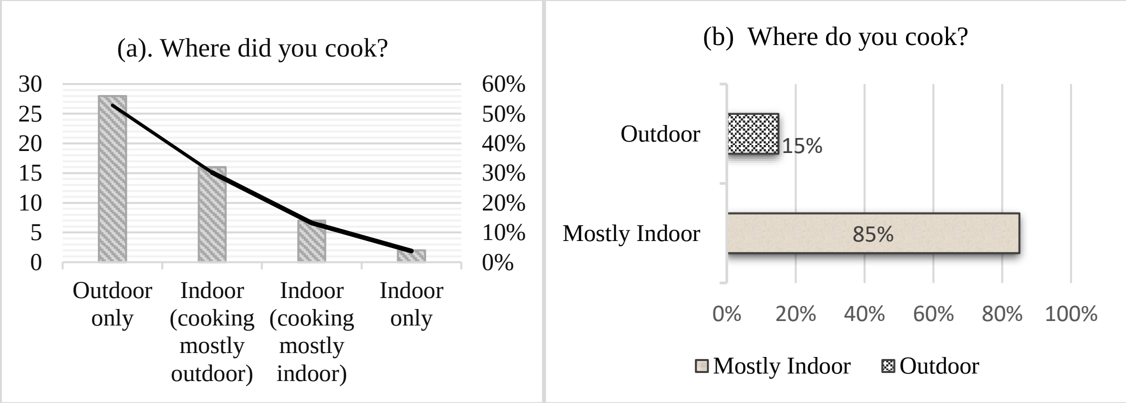


Figure 4.5 (a) and (b) show the frequency and percentage of where households cook food before and during the study

Source: Author, 2022

4.2.6 Access to electricity and other energy sources

Figure 4.6 shows that around 58% of households in the study are not connected to the national grid and 42% are connected.

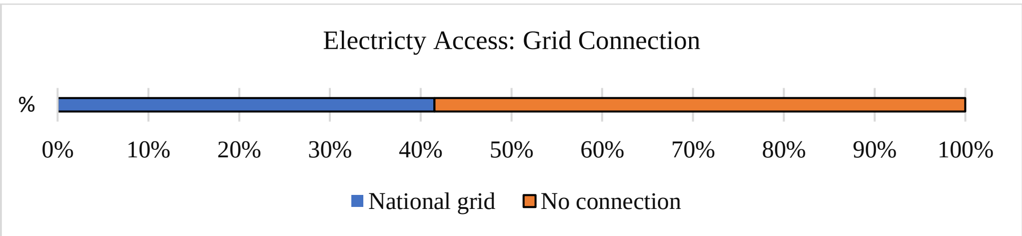


Figure 4.6 Access to electricity

Source: Author, 2022

Alternative energy sources especially for lighting are used by households who are either connected to the national electricity grid or not. Figure 4.7 shows that disposable batteries are the most commonly used, followed by solar home systems, pico solar lights and rechargeable batteries.

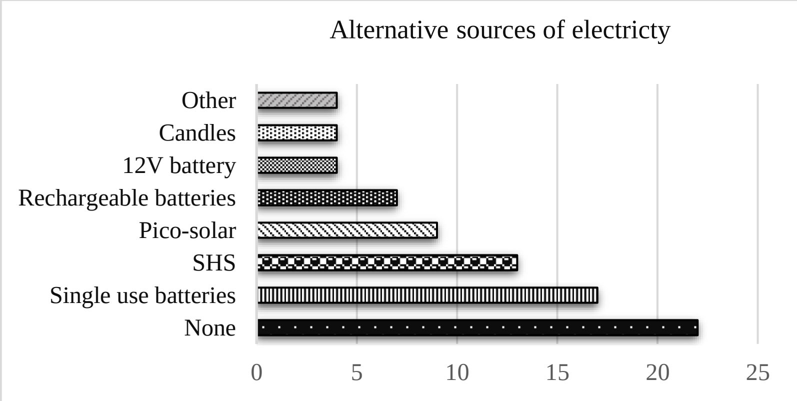


Figure 4.7 Shows the alternative sources of electricity used in the study Areas

Source: Author, 2022

4.2.7 Cooking fuel and device preference

Figure 4.8 shows that overall, charcoal and firewood are undesirable fuels for cooking. Most participants (approximately 40% and 80%) were not happy when using firewood and charcoal fuels respectively. Few respondents at 15% and 10% were generally happy while the rest provided neutral responses and others did not know.

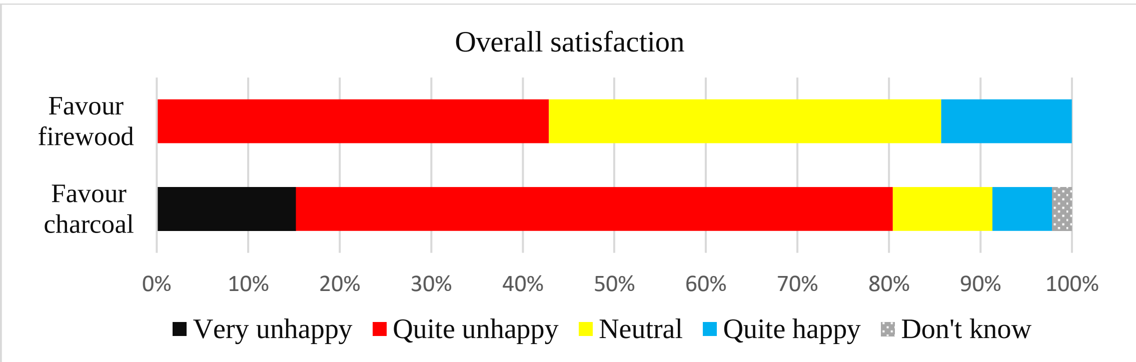


Figure 4.8 Overall satisfaction of households on the use of firewood and charcoal in the study Areas

Source: Author, 2022

Respondents were asked to indicate their views/beliefs regarding the stove they use most often (using a 5-point Likert scale) on six items namely cleanliness, speed of cooking, cost, ease of cooking, versatility and safety as shown in Figures 4.9, 4.10, and 4.11, respectively. More specifically for charcoal users, 80% were generally unhappy with the current situation, 84% consider charcoal to be dirty and 95% consider it to be slow, 97% consider charcoal to be expensive fuel for cooking. The results also show that 54% of charcoal users face ignition challenges when using the fuel hence not easy for cooking. 80% of charcoal users consider it to be unsafe for cooking while 84% consider the fuel as versatile. Participants gave positive feedback for the speed and cost of cooking on firewood and the versatility of cooking on either firewood or charcoal.

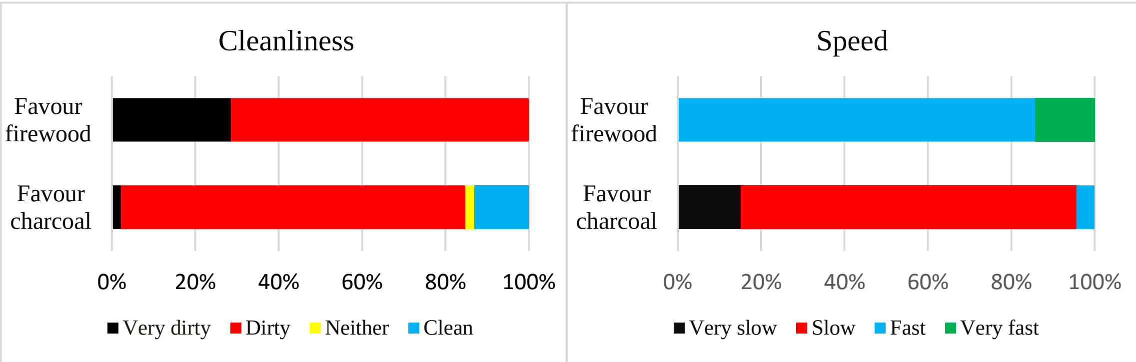


Figure 4.9 Fuel Cleanliness and speed of cooking

Source: Author, 2022

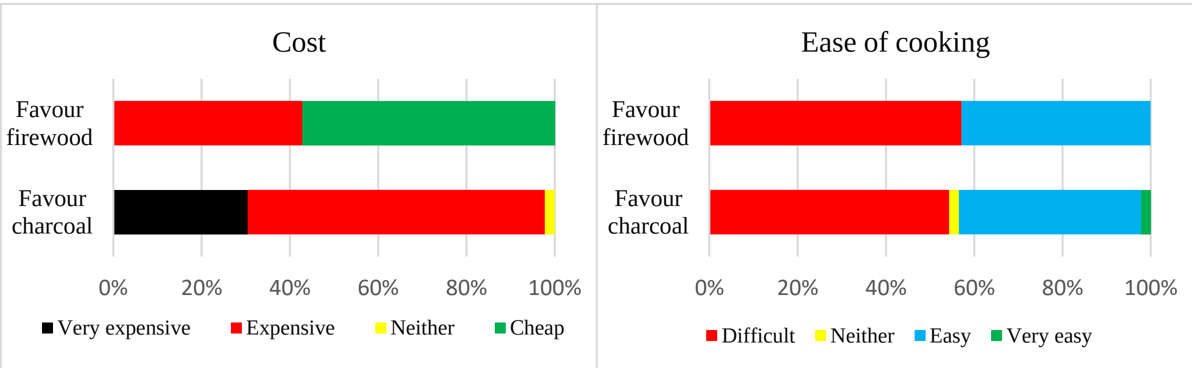


Figure 4.10 Fuel cost and ease of cooking

Source: Author, 2022

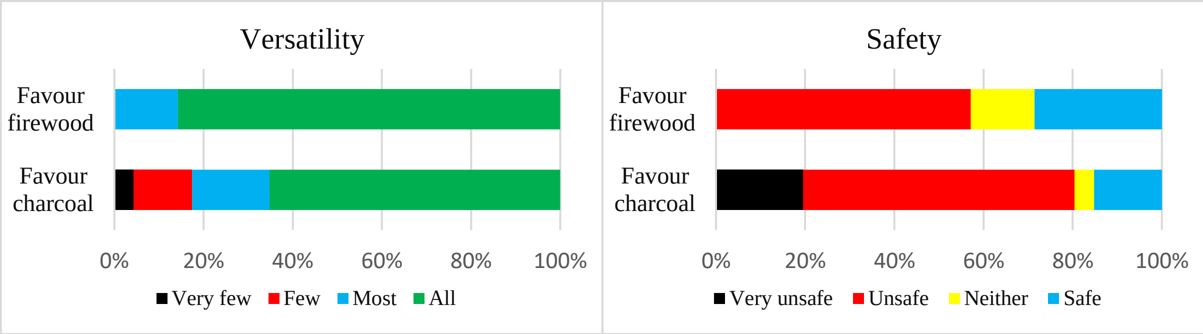


Figure 4.11 Fuel versatility and safety.

Source: Author, 2022

4.2.8 Challenges associated with existing cooking fuels

The participants mentioned some challenges they face when using charcoal. The fuel takes more time to be ignited more especially depending on the type of trees/wood used to produce charcoal. Moreover, when there is inadequate air circulation, the charcoal takes longer to completely catch fire. Charcoal becomes more expensive to buy especially during the rainy season ending up not fulfilling what was intended to be cooked by those who cannot afford to buy a sack bag of the charcoal.

The cooking process takes longer to be completed with only a few dishes cooked especially when poor quality charcoal has been used. Plastic papers that are used to ignite charcoal are sometimes difficult to find and this delays the process of cooking. Several problems encountered when using firewood were pointed out by respondents. It was reported that wet firewood is difficult to use for cooking as it does not catch fire easily instead the fuel produces a lot of smoke. Burning firewood produces a lot of smoke that is toxic and may irritate the eyes and cause respiratory problems to the cook. The smoke produced when using firewood makes utensils dirtier as compared to charcoal.

Respondents reported that cooking utensils (pots, pans etc.) deteriorate faster and can melt when used frequently on a stove using maize bran briquettes due to intense heat released from burning the fuel. Persistent electricity blackouts interrupt the cooking process. Also, participants think that the price of electricity is high and excessive to be used for daily cooking.

4.2.9 Household expenditures on charcoal and firewood

Figure 4.12 shows that fuel expenditure differed significantly for households that used firewood most often than charcoal. Households spend between 3,000 and 7,000MWK per month for firewood and 10,000 and 16,000MWK per month for charcoal. However, in this study, it appears to be, to some extent, due to those households which cook with firewood most often, having much lower household incomes. It, therefore, appears that households cook with firewood out of necessity (as they have less income) rather than due to preference for the fuel.

Generally, households with lower incomes spend a larger percentage of their income on cooking fuels than those with higher incomes. For charcoal users, most households spend between 8% and 26% on cooking fuels, while firewood users (with significantly lower household incomes) spend between 8% and 16% on cooking fuels. Families with habits of cooking or reheating food more often are likely to spend more money on purchasing cooking fuels (Kanangire *et al*., 2016).

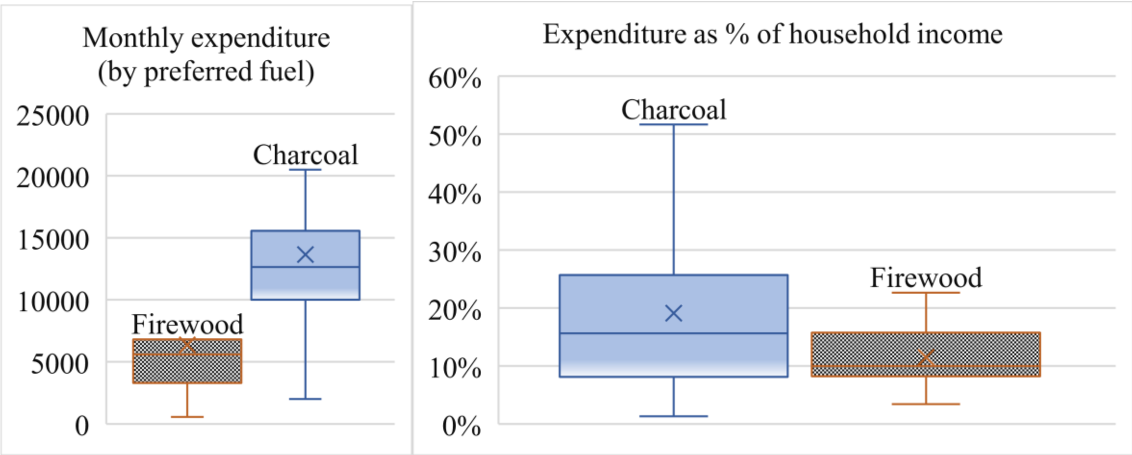


Figure 4.12 Household expenditure on cooking fuels

Source: Author, 2022

With regards to the frequency of fuel purchases, Figure 4.13 shows that nearly 50% of charcoal or firewood users purchase daily, followed by 20% that purchase monthly. This closely mirrors the pattern of household incomes, where the majority of respondents received daily, followed by monthly, incomes.

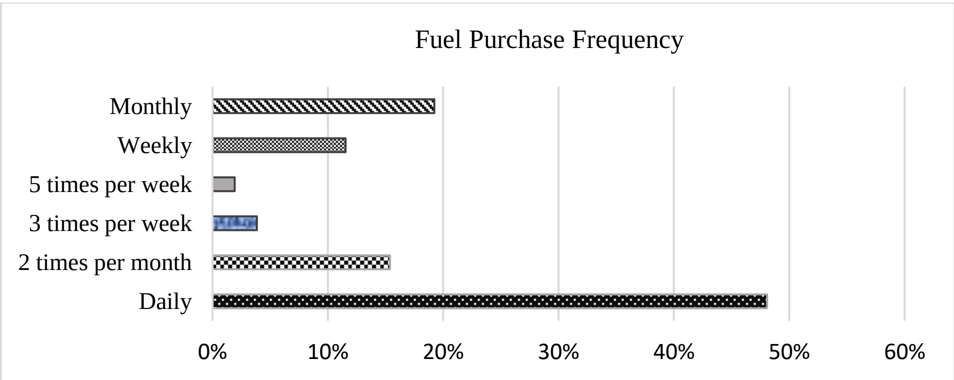


Figure 4.13 The rate of purchasing cooking fuels

Source: Author, 2022

4.2.10 The choice of using cooking fuels

Consumers have the choice of either switching or using multiple fuels and sometimes continue only with their existing fuels. Switching fuels in this study refers to an action of which households choose to minimize or completely cease using fuelwoods and adopt modern fuel/stoves as a cooking replacement. The study participants were also asked about switching to more modern cooking fuel like LPG and electricity but their responses were mixed.

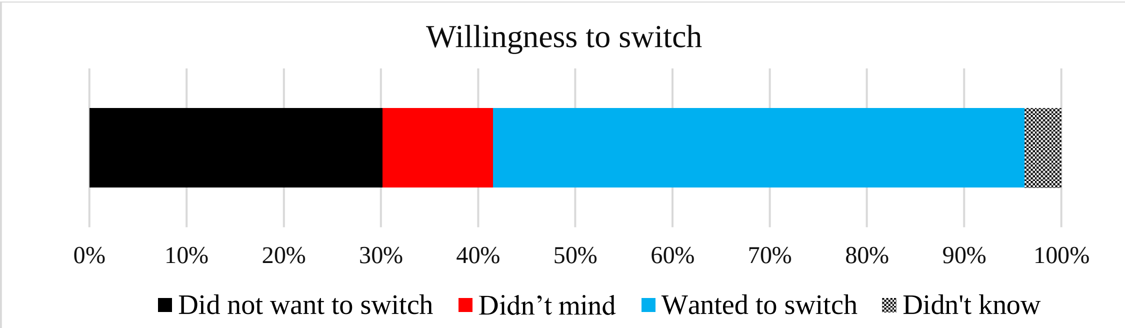


Figure 4.14 The willingness of consumers to switch to modern cooking fuels

Source: Author, 2022

As indicated in Figure 4.15(a) respondents have impressions that modern fuels are environmentally friendly, clean, easy to use, and can cook faster at any place. However, 15% expressed safety concerns such as explosions and leakages. These issues were also reported in India by Gould and Urpelainen (2018) though incidents of explosions are rare, safety precautions should be habitually observed. The barriers of switching to modern fuels in Figure 4.15(b) shows that almost 58% of respondents said that fuels and stoves are too expensive, 49% do not have access to modern fuels and 30% said they do not know much about modern cooking fuels such as ethanol briquettes and liquefied petroleum gas. This aligns well with Affordability, Accessibility and Awareness which are key to the adoption of any new technology.

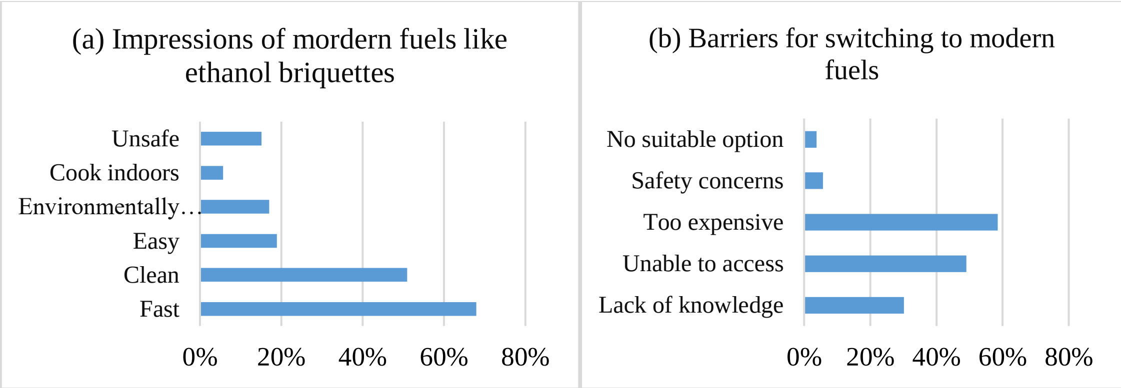


Figure 4.15 (a) and (b) shows the impressions of modern cooking fuels and the barriers for switching, respectively

Source: Author, 2022

Previous studies discussed that lack of knowledge and accessibility are serious barriers to the adoption of modern fuels (ESMAP, 2020; Zuzarte, 2007). Modern cooking fuels and stoves are very expensive especially when markets are not near to the households. The costs of electricity and LPG among others are a significant barrier among poor people hence limiting adoption and use *(*Pye *et al*., 2020). A study by Puzzolo (2013) also found that lack of availability and stable supply affect the adoption and use of modern fuels. Besides, limited awareness of the benefits of clean cooking fuels like ethanol is a barrier to adoption.

4.3 Assessing the performance and efficiency of cooking fuels and stoves

The comparative results on the technical performance of the ethanol briquettes and charcoal with different stove models are presented herein. The results in the subsections below address the first objective of the study which is to assess the technical performance of ethanol briquettes and charcoal with different stove models to determine if existing models can be used with or without adaptations.

4.3.1 Design and construction of combustion chambers

Five prototypes of combustion chambers (Figure 4.16) were constructed and tested in this study. Two containers labelled A for Chitetezo Mbaula stove and D for Kenya Ceramic Jiko were the chambers that gave the highest thermal efficiency and low fuel consumption. Prototype of combustion container A has a precise diameter of 11.5cm and 4cm in height. The surface area is 103.816 cm^2 while the circumference is 36.11 cm. The height of stands for the container is 10cm. Having similar dimensions apart from container height of 5cm and without stands, both chambers A and D required a gap of 2.875cm between the pot bottom and the top edge of the container to allow air circulation.

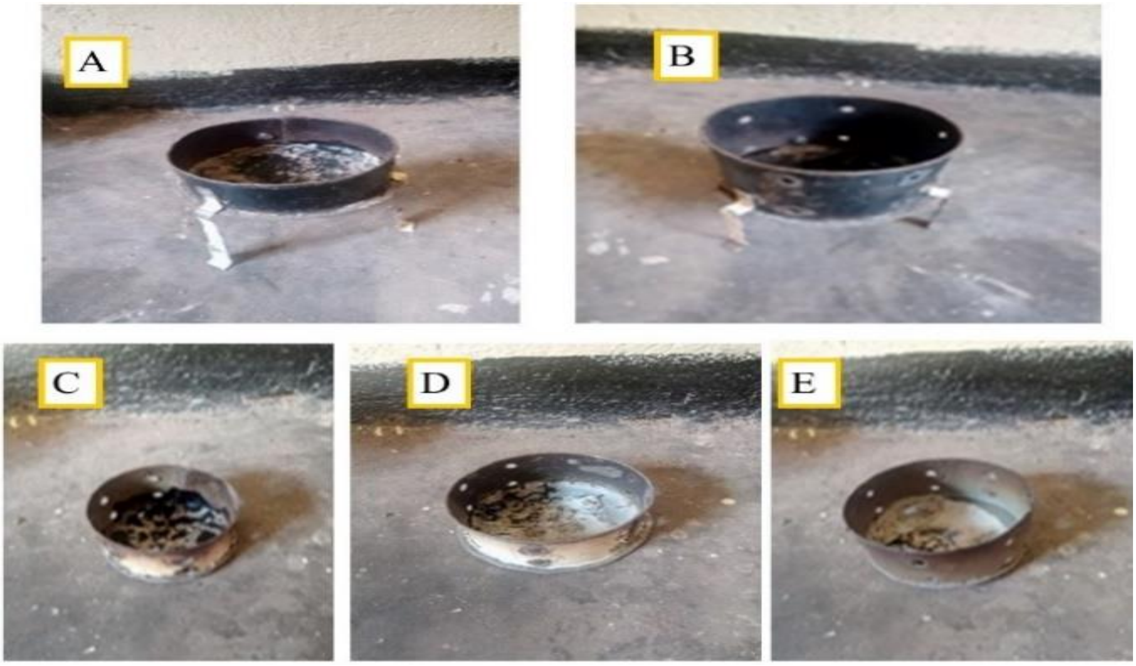


Figure 4. 16: The combustion chambers.

Source: Author, 2022

Table 4.3 shows the results of the water boiling test conducted on the two stoves. Chitetezo Mbaula stove (Test A), has an excellent performance which is evident by the short time taken to boil water, in 9 mins, with more briquettes (2.5 blocks) weighing

67.5g. Despite the container having no holes, the inside space of the Chitetezo Mbaula stove aid free air circulation to burn the fuel. The volume of the container ($415.265cm^3$) is adequate to burn the fuel without any leakages. Besides, the height of the container and stand provided a reasonable gap of 2.875cm between the bottom/ base of a pot and the top edge of the combustion container.

The properties of the container in Test B have contributed to its poor performance. As indicated in the table, both the number of blocks (3) and the weight of briquettes (81g) used are high. The presence of holes and big volume (859.664 cm^3) contribute to both fuel leakage and overconsumption since it requires more fuel. Too much airflow caused some heat loss thereby increasing the time to boil water, 12 mins. The performance of the Kenya Ceramic Jiko stove (Test D) is the best as it takes considerably less time and fuel (11 mins and 2 blocks) to boil water.

As compared to Tests C and E, the large volume of the container ($519.080cm^3$) in Test D prevents overflow and leakage while the holes on its sides allow air to flow in and burn the fuel. In general, the fuel consumption and use in all trials except two tests were 2 briquettes (54g). Based on the tests so far, specifically considering the start time of boiling and the length of time the flame was sustained, the study found that designs in tests A and D performed well. Besides, Chitetezo Mbaula is quicker but uses slightly more fuel than the Kenyan Ceramic Jiko. Figure 4.17 display functioning combustion containers labeled (A) for Chitetezo Mbaula and (D) for Kenya Ceramic Jiko stoves.

Figure 4.17 Presentation of functioning ethanol briquettes cookstoves

Source: Author, 2022

The container-pot gap is necessary for the combustion of any remaining gases by secondary air and the transfer of heat energy. The results in Table 4.3 show that when the pot gap is too big then there is diminished heat transfer, while a small gap contribute to insufficient air flow which is crucial for clean combustion. Oketch (2013) reported that the size of pot gap influences the stove firepower. This study has found that the existing stoves burn fuel efficiently. The design of containers and how they have been retrofitted with the stoves meet the preferences of users. Just like a study in Kenya (Treiber, 2011), the efficiency of ethanol briquettes fuel and the stoves would gain widespread use and popularity because have met the demands of the households.

Table 4.3 Characteristics of combustion containers for Chitetezo Mbaula and Kenya Ceramic Jiko Stove models

Stove type	Chitetezo Mbaula container without holes	Chitetezo Mbaula container with holes	KCJ Small container with holes	KCJ Large container with holes	KCJ Medium container with holes
	Test A	Test B	Test C	Test D	Test E
Container Diameter (cm)	11.5	11.7	8	11.5	10.5
Container Height (cm)	4	8	4.2	5	5.5
Volume (cm^3)	415.265	859.664	211.008	519.080	476.003
Area of container (cm^2)	103.816	107.458	50.24	103.816	86.546
Circumference (cm)	36.11	36.74	25.12	36.11	32.97
Stand Height (cm)	10	7.5	N/A	N/A	N/A
Pot gap (cm)	2.875	2.925	2	2.875	2.625
Quantity of water in litres	1	1	1	1	1
Number of briquettes	2.5	3	2	2	2
Weight of briquettes (g)	67.5	81	54	54	54
Start Time	7:17	6:17	6:41	6:59	10:35
Boil Time	7:26	6:29	6:53	7:10	10:50
End Time	7:26	6:34	6:53	7:12	10:58
Time to Boil (mins)	9	12	12	11	15
General Observation	The flames started dying out when the water had started bubbling on top.	A third briquette was added at 10 minutes and the fuel consumption was very high	Fuel spilt through the bottom holes. The fire started to die when bubbles appeared. The combustion chamber was too small	The container covered some stove air vents. It cannot burn properly if a bigger pot is used since it blocks the air coming from the top part.	Had relatively enough air coming from the bottom and top of the stove.

Source: Author, 2022

4.3.2 *Physico-chemical properties of fuels*

Table 4.4 shows the calorific values, carbon and moisture contents of ethanol briquettes and charcoal fuels. The table shows that ethanol briquettes have high calorific values as compared to charcoal. A high calorific value shows the ability of a fuel to release a significant amount of heat. The results showed that Charcoal fuel contains high carbon content as compared to ethanol briquettes. The ethanol briquettes have a high moisture content of 17% not only because of their inherent nature but as reported by other studies (Feng *et al.*, 2019) the water content helps to speed up the oxidation reaction. On the other hand, charcoal had a 1.7 percent moisture and this variation when compared with other studies might be caused by different quantities of air humidity from the surrounding (Faxälv, 2007).

Table 4.4 Characterization of fuel contents

	Ethanol Briquettes	Charcoal
Gross Calorific Value (HHV, MJ/Kg)	37.443	23.799
Net Calorific Value (LHV, MJ/Kg)	36.123	22.479
Carbon content by mass (g)	0.522	0.950
Moisture content (%) on wet basis	17	1.7

Source: Author, 2022

4.3.3 *Water boiling tests*

The results of water boiling tests on stove characteristics show the burning rate and efficiency and performance parameters that include time to boil 1 L of distilled water and specific fuel consumption.

4.3.3.1 Time to boil

Figure 4.18 shows that ethanol briquettes boiled water faster when paired with Chitetezo Mbaula seconded by Kenya Ceramic Jiko and finally charcoal stove. The presence of a lid on a pot helped to lower the time taken to boil water in all experiments by 12.25, 8.17 and 27.49 mins than when the lid was off the pot. Temperature corrected time to boil is the adjusted time to reflect a temperature rise of 75 °C from start to boil (Hajamalala, 2014). The results (Table 4.5 and 4.6) show that there is a significant difference in time to boil in all the stove comparisons since p = 0.0001.

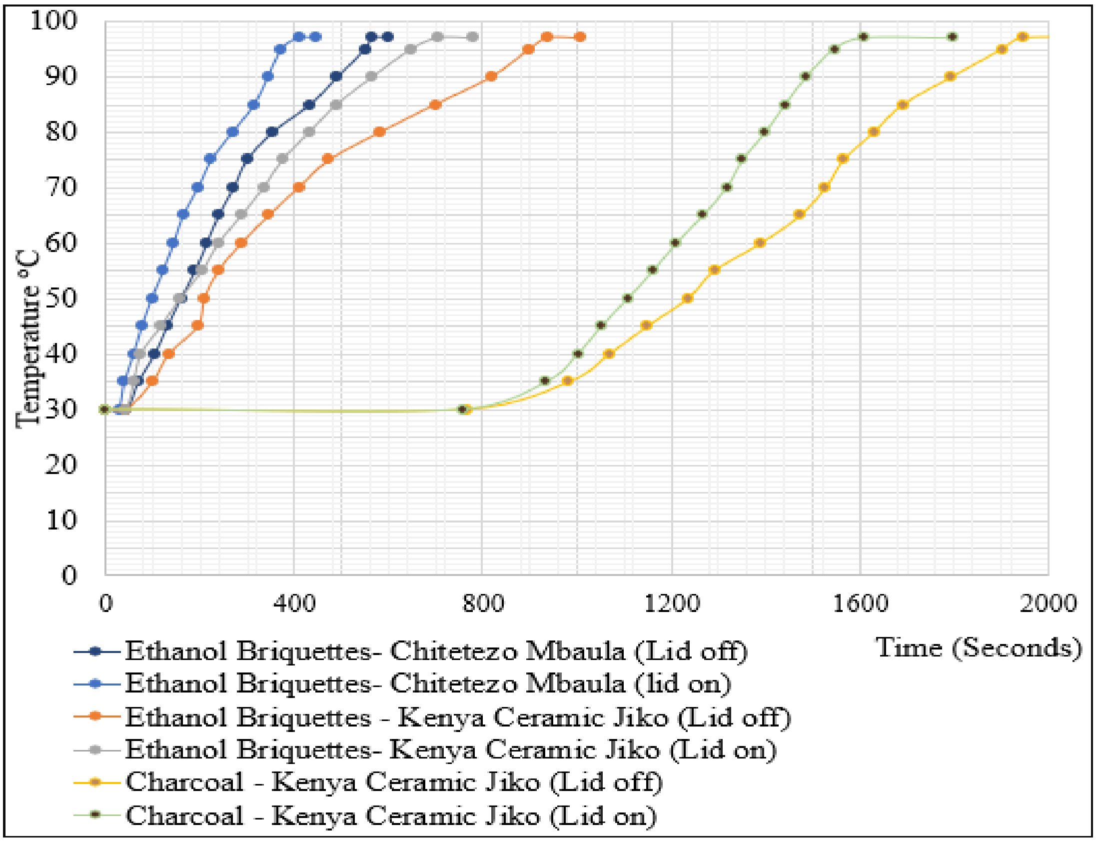


Figure 4.18 The time taken to boil distilled water

Source: Author, 2022

4.3.3.2 Burning rate

Figure 4.19 show the burning rate of the stoves when using different fuels. Burning rate is the amount of fuel in grams burned per minute in a stove. The results of the lid on and lid off treatments show that at least 3 and 8 grams of ethanol briquettes were burned per minute in Kenya Ceramic Jiko and Chitetezo Mbaula stoves respectively. The burning rate for the charcoal in the Kenya Ceramic Jiko stove is at 6 and 7 grams per minute the pot lid is off and on, respectively. These results indicate that the Chitetezo Mbaula stove burns ethanol briquettes rapidly.

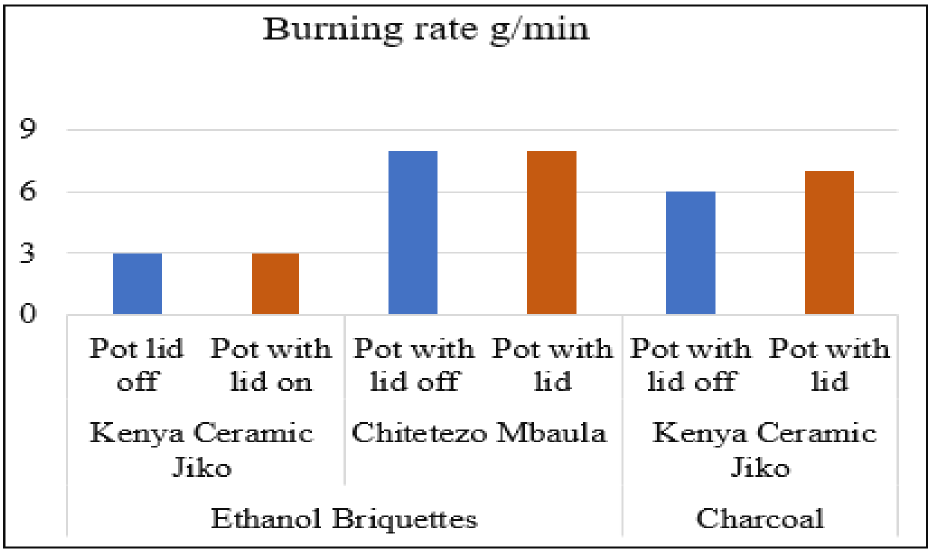


Figure 4.19 Burning rate of fuels in stoves

Source: Author, 2022

Table 4.6 shows that the burning rates in all tests are statistically significant since all the p-values in all stove comparisons are less than alpha 0.05. This indicates that the burning rates of ethanol briquettes in both Chitetezo Mbaula and Kenya Ceramic Jiko stoves are greater than that of charcoal in Kenya Ceramic Jiko stove.

4.3.3.3 Thermal efficiency

The thermal efficiency of a stove is a measure of the fraction of heat produced by the fuel that is absorbed directly by the water in the pot. Higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot (Boafo-Mensah *et al.*, 2013). Table (4.5) and (4.6) shows that the statistical differences of thermal efficiency of the stoves are not significant since the p-values are greater than alpha 0.05. This indicates that the thermal efficiency of charcoal in Kenya Ceramic Jiko is the same as ethanol briquettes in both Chitetezo Mbaula and Kenya Ceramic Jiko stoves.

The study found that Kenya Ceramic Jiko stove with ethanol briquettes have 94.46 % and 96.31% thermal efficiency with the lid off and lid on pot, respectively. Furthermore, Chitetezo Mbaula with ethanol briquettes has 62.29% and 77.89% thermal efficiencies with the lid off and lid on pot, respectively. For charcoal in Kenya Ceramic Jiko stoves, 49.52% and 50.07% thermal efficiencies are observed in pot with the lid off and lid on, respectively. These results indicate that a higher percentage 50.48% and 49.93% of charcoal energy is lost to the environment as compared to 5.54% and 3.69% for Kenya Ceramic Jiko, while 37.71% and 22.11% for Chitetezo Mbaula with the lid off and lid on respectively (see Table 4.5). It can be observed that from the results that Kenya Ceramic Jiko is a more energy-saving stove with high thermal efficiency, and less energy is lost to the environment.

4.3.3.4 Specific fuel consumption

Specific fuel consumption is the exact amount of fuel either ethanol briquettes or charcoal used to bring a litre of water to a boil by starting with a cold stove. In Figure 4.20, the number of ethanol briquettes used in the Kenya Ceramic Jiko stove showed the lowest overall weight of 41g and Specific fuel consumption of 11g with the lid on. Despite conducting the test under similar settings and treatment, Chitetezo Mbaula used ethanol briquettes fuel weighing 71g but the specific fuel consumption was 13g. When 500g of charcoal was in put in Kenya Ceramic Jiko, 27g was used specifically to boil 1 litre of water. This is due to the difference in stove design and the cooking fuel.

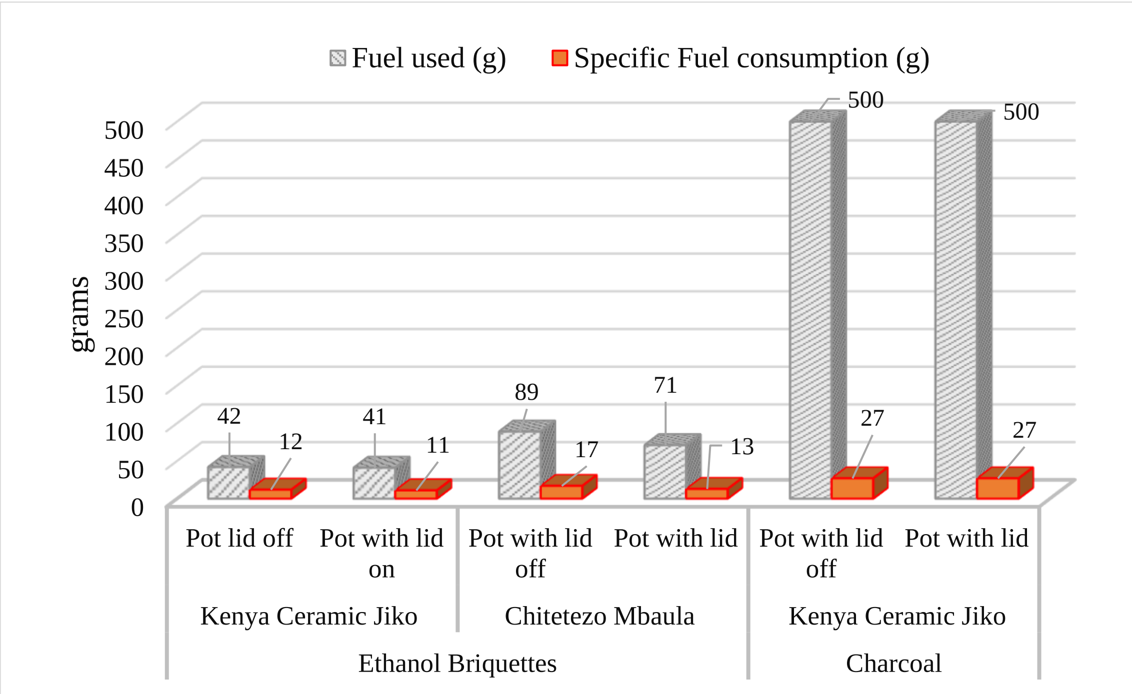


Figure 4.20 Quantity of fuel used and specific fuel consumption.

Source: Author, 2022

In Table 4.5, the results show that specific fuel consumption (SFC) using the lid off treatment is statistically significant ($p = 0.0465$) when charcoal in Kenya Ceramic Jiko is compared with ethanol briquettes. This indicates that the SFC of charcoal in Kenya Ceramic Jiko is different than that of ethanol briquettes in Kenya Ceramic Jiko stoves. However, there is no significant difference in SFC ($p = 0.2440$) when charcoal in Kenya Ceramic Jiko is compared with ethanol briquettes in Chitetezo Mbaula. Similarly, the difference in SFC of ethanol briquettes is not statistically significant (p=0.6058) when Chitetezo Mbaula is compared with Kenya Ceramic Jiko stove. In both cases, it observed that the SFC of charcoal in Kenya Ceramic Jiko is not equal to that of ethanol briquettes in Kenya Ceramic Jiko and Chitetezo Mbaula stoves. The results (Table 4.5) shows that specific temperature of fuel consumption corrected (TC-SFC) at 75^{o}C and the temperature corrected specific energy consumption (TC-SEC) is high when charcoal is used to boil 1 litre of water as compared to ethanol briquettes in Chitetezo Mbaula and Kenya Ceramic Jiko stoves.

4.3.3.5 Firepower

Firepower (FP) is the ratio of the fuel energy consumed by the stove (Watts) per unit time. The study found Ethanol briquettes in Chitetezo Mbaula had high firepower 5114 W and 5051 W lid off and lid on pot, respectively. This was seconded by Charcoal in KCJ with firepower of 2147 W and 2466 W with lid off and lid on pot, respectively. The last one was Ethanol briquettes in KCJ with firepower of 1558 W and 1993 W lid off and lid on treatments respectively (Table 4.5). Although using the same fuel type, the stove firepower generated by Chitetezo Mbaula is much greater because it was burning fuel quickly than Kenyan Ceramic Jiko.

The results show that firepower increase when fuel usage and consumption also increase. Therefore, there is a direct positive relationship or proportionate for these variables a rise in one result in an increase in the other. The study found that the firepowers of all stoves are statistically significant in all comparisons since the p-values are less than alpha 0.05 (see Table 4.6). This shows that the firepower of charcoal in Kenya Ceramic Jiko is not the same as ethanol briquettes in both Chitetezo Mbaula and Kenya Ceramic Jiko stoves.

4.3.3.6 Stove usability and flame control

The study found that cooking using Chitetezo Mbaula and Kenya Ceramic Jiko stoves was easy when the ethanol briquettes were used. However, it was observed that ethanol briquettes could not sustain the fire once consumed completely unlike charcoal, thus requiring an immediate refilling of the stove to ensure the continuation of flame. It was also observed that ethanol briquettes were easy to ignite than charcoal. This is because denatured ethanol (80-95%) has a low flash point of 8-23 ℃ (BCB International, 2015) as compared to charcoal which is above 300 ℃.

Figure 4.21 Residue from ethanol briquettes

Source: Chomanika *et al.*, 2022

4.3.3.7 Flame distribution

The study examined that flame and heat distribution of the stoves when using both ethanol briquettes and charcoal. These heat transfer mechanisms have also been studied by other researchers such as Kumar, Kuma and Tyagi (2013). In the experiment for Kenya Ceramic Jiko, when subjected to moderate breeze, fire blazed direct to the middle bottom point of the pot, but this was not the case with Chitetezo Mbaula, where it was observed that the flame was evenly distributed on both the bottom and up the sides of a pot. In all the three stove and fuel combinations, it was observed that not all fuel energy consumed during cooking is transferred to the pot and this because of part of the flame flew up to the sides of the pots. Some heat is also lost to the environment due to the big gap between the stove and combustion container.

Figure 4.22 Flame distribution

Source: Chomanika *et al.*, 2022

Table 4.5: Comparative analysis of the performance and efficiency of three cookstoves and their fuels

	Pot treatment (lid off)			Pot treatment (lid on)			P-value
	Average	St dev	COV	Average	St dev	COV	
Ethanol briquettes in Kenya Ceramic Jiko							
Time to boil (min)	16.06	0.0	0.2%	12.25	0.1	0.8%	0.0001
Temp-corrected time to boil (min)	18	33.5	186.4%	14	25.6	186.7%	0.8774
Burning rate (g/min)	3	0.0	1.8%	3	0.1	1.9%	1
Thermal efficiency (%)	94.4%	36.47%	38.6%	96.31%	38.47%	39.9%	0.9547
Specific fuel consumption (g)	12	9.0	78.5%	11	8.8	78.5%	0.8972
Temp-corrected SFC (g)	11	5.4	49.2%	11	5.2	49.1%	1
Specific energy cons. (kJ/kg)	394	194.0	49.2%	384	188.2	49.1%	0.9520
Firepower	1558	27.5	1.8%	1993.5	37.3	1.9%	0.0001
Ethanol briquettes in Chitetezo Mbaula							
Time to boil (min)	10.02	0.1	0.7%	8.17	0.2	3.0%	0.0001
Temp-corrected time to boil (min)	11	20.1	185.5%	9	16.2	180.8%	0.8997
Burning rate (g/min)	8	0.3	4.1%	8	0.2	2.3%	1
Thermal efficiency (%)	62.2%	11.20%	18.0%	77.89%	14.03%	18.0%	0.2067
Specific fuel consumption (g)	17	12.6	76.1%	13	10.1	76.1%	0.6900
Temp-corrected SFC (g)	15	3.1	20.8%	12	2.5	20.8%	0.2375
Specific energy cons. (kJ/kg)	541	112.8	20.8%	432	89.9	20.8%	0.2607
Firepower	5114.6	210.4	4.1%	5051.0	116.2	2.3%	0.6701
Charcoal in Kenya Ceramic Jiko							
Time to boil (min)	32.22	0.5	1.6%	27.49	0.8	3.1%	0.0010
Temp-corrected time to boil (min)	36	0.6	1.6%	31	0.9	3.1%	0.0013
Burning rate (g/min)	6	0.2	4.0%	7	0.3	4.8%	0.0086
Thermal efficiency (%)	49.5%	2.50%	5.0%	50.07%	0.96%	1.9%	0.7400
Specific fuel consumption (g)	27	1.5	5.5%	27	0.6	2.2%	1
Temp-corrected SFC (g)	31	1.7	5.5%	30	0.6	2.2%	0.3911
Specific energy cons. (kJ/kg)	691	37.9	5.5%	676	14.6	2.2%	0.5572
Firepower (watts)	2147.4	85.5	4.0%	2466.5	118.1	4.8%	0.0193

Source: Chomanika *et al.*, 2022

The results in Table 4.6 were obtained from t-test. The test was used to compare the means of boiling water using ethanol briquettes and charcoal in Chitetezo Mbaula and Kenya Ceramic Jiko stoves. The results on the probability values (p-values) from the comparisons that are less than 0.05 show a significant difference between the variables.

Table 4.6 The comparison of ethanol briquettes with charcoal in Chitetezo Mbaula and Kenya Ceramic Jiko stoves (Probability values are significant at 0.05)

Comparison	Using charcoal and ethanol briquettes in Kenya Ceramic Jiko stoves	Using charcoal in Kenya Ceramic Jiko and ethanol briquettes in Chitetezo Mbaula stove	Using ethanol briquettes in Chitetezo Mbaula and Kenya Ceramic Jiko stoves
Time to boil	0.0001	0.0001	0.0001
Burning rate	0.0001	0.0007	0.0001
Thermal efficiency	0.1003	0.1262	0.2179
Specific fuel consumption	0.0465	0.2440	0.6058
Firepower	0.0030	0.0001	0.0001

Source: Author,2022

4.3.4 Comparing the controlled cooking tests

Controlled cooking tests for a complete meal (Nsima, Beef and Vegetables) were replicated three times. Table 4.7 shows the results. The results show that the specific fuel consumption for charcoal in Kenya Ceramic Jiko is very high (665g/kg) compared to that of ethanol briquettes in Kenya ceramic Jiko (453g/kg) and Chitetezo Mbaula (477g/kg). The time taken to cook a meal using ethanol briquettes was shorter (95 min) when Chitetezo Mbaula stove was used followed by Kenya Ceramic Jiko (112 min) and finally charcoal (128min). The results (Table 4.8) show that there are no significant differences in the time taken to cook a meal. However, the differences in specific fuel consumptions in all stoves are statistically significant at 95% confidence level.

Table 4. 7: Controlled Cooking Test for a complete meal.

Fuel Type	Stove Model	CCT results:	Fuel used (g)	Total weight of food cooked (g)	Specific fuel consumption (g/kg)	Total cooking time (min)
Charcoal	Stove 1: Kenya Ceramic Jiko	Mean	1,300	1,955	652	128
		St Dev	-	7	2	23
		COV	-	0.4%	0.3%	18%
Ethanol briquettes	Stove 2: Kenya Ceramic Jiko	Mean	882	1,946	453	112
		St Dev	-	12	3	23
		COV	-	0.6%	0.7%	21%
	Stove 3: Chitetezo Mbaula	Mean	929	1,947	477	95
		St Dev	-	21	5	11
		COV	-	1.1%	1.04%	12%

Source: Author,2022

Table 4.8 shows the results on quantity of fuel used and specific fuel consumption. A comparison of charcoal in Kenya Ceramic Jiko and ethanol briquettes in Kenya Ceramic Jiko stove show a t-test value of 95.59 and a significant probability value (0.0001). The results from a comparison of Charcoal in Kenya Ceramic Jiko stove and ethanol briquettes in Chitetezo Mbaula stove show a T-test equal to 56.69 (p-value 0.0001). When the consumption of ethanol briquettes in Kenya Ceramic Jiko is compared to Chitetezo Mbaula, the T-test is 9.56 (p-value 0.0020). Since all p-values are less than alpha 0.05, it means that the specific fuel consumptions are different in all the stoves.

The total time taken to cook a meal using charcoal in Kenya Ceramic Jiko is longer but when compared to ethanol briquettes in Kenya Ceramic Jiko the difference is not statistically significant since the t-test is 0.87 with (p-value 0.4422). Similarly, when charcoal in Kenya ceramic Jiko is compared to Chitetezo Mbaula the T-test of 2.25 gives the p-value of 0.0884. Furthermore, when the time taken to cook a meal using ethanol briquettes in Kenya ceramic Jiko is compared to Chitetezo Mbaula the T-test is 1.15 with a p-value of 0.3124. Therefore, the results show that there are no significant differences in the total cooking time in all the stove comparisons.

Table 4.8 Statistical variations of parameters in Controlled Cooking Tests

Comparison	Parameter	Percentage difference	t-test	P-value	Sig @ 95% CI?
Charcoal in Kenya Ceramic Jiko stove (1) versus ethanol briquettes in Kenya Ceramic Jiko stove (2)	Specific fuel consumption (g/kg)	32%	95.59	0.0001	Yes
	Total cooking time (min)	13%	0.87	0.4422	No
Charcoal in Kenya Ceramic Jiko stove (1) versus ethanol briquettes in Chitetezo Mbaula stove (3)	Specific fuel consumption (g/kg)	28	56.69	0.0001	Yes
	Total cooking time (min)	26%	2.25	0.0884	No
Ethanol briquettes in Kenya Ceramic Jiko Stove (2) versus Chitetezo Mbaula stove (3)	Specific fuel consumption (g/kg)	5%	9.56	0.0020	Yes
	Total cooking time (min)	-17%	1.15	0.3124	No

Source: Author,2022

The Focus Group Discussions allowed participants in the study to give feedback on the technical performance and potential modifications that could be made. Participants reported that ethanol briquettes performed well but differently on both cookstoves used in the study. All the study participants further noted that fuel consumptions were high at all times on Chitetezo Mbaula cookstove when cooking meals compared to Kenya Ceramic Jiko. However, cooking using Chitetezo Mbaula was quicker than Kenya ceramic Jiko.

4.3.5 Emissions tests (indoor air pollution)

Carbon monoxide and particulate matter (2.5) µm were measured based on WHO benchmarks for indoor air pollution. The maximum limits for CO are marked at 20g/min for charcoal stoves and 0.07g/min for ethanol stoves. Also, particulate matter is benchmarked at 1500g/min for charcoal stoves and 0.15mg/min for ethanol stoves (Berko, 2018).

4.3.5.1 Carbon monoxide

The graphical representation (Figure 4.23) shows the real-time record of emissions from charcoal in the Kenya Ceramic Jiko stove. The results indicate that carbon monoxide exceeds the maximum WHO benchmark of 20g/minute. The total CO emissions (Figure 4.24) were collected from the stove in 60 minutes and weighed 1242.68 grams. On average 20.711 grams of CO were released per minute which is relatively higher than the recommended benchmark of 20g/min. High CO emissions pose high health risks to the users. The study shows that there is an increase by 3.55% between the actual test and the WHO recommended maximum benchmark.

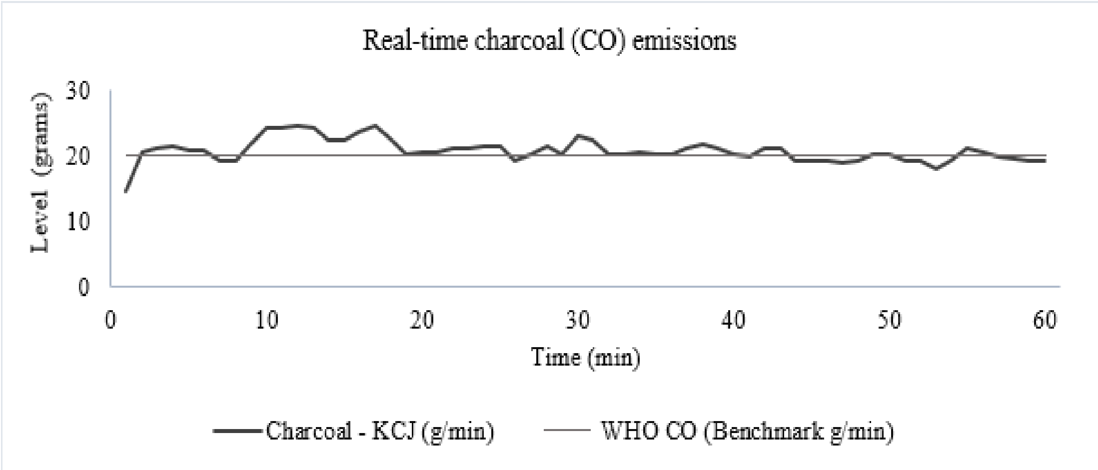


Figure 4.23 Representation of Carbon Monoxide emissions from Charcoal-KCJ Stove

Source: Author,2022

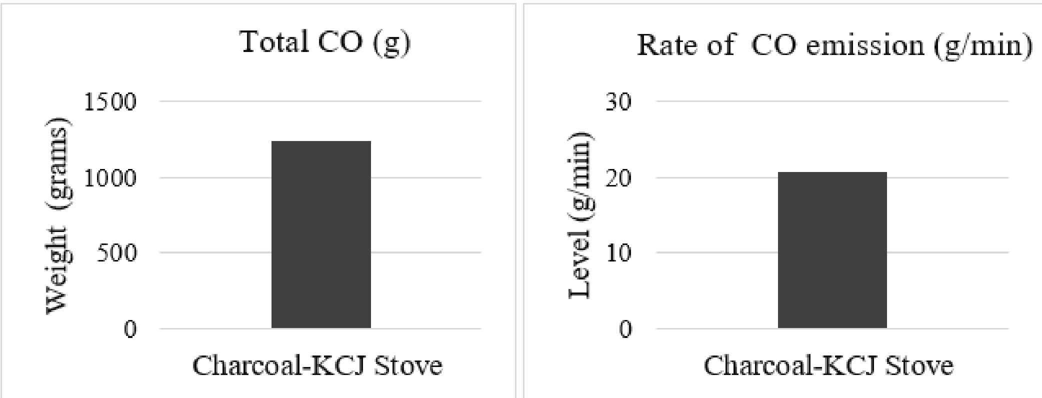


Figure 4.24 Levels of CO emissions from Charcoal stove

Source: Author,2022

The results in Figure 4.25 show the real-time trends of CO emissions from ethanol briquettes in both stoves. The results display that CO exhausts were relatively less in KCJ stove than Chitetezo Mbaula. The proposed WHO benchmark rated at 0.07g/min was not reached in both tests. The computed values show that the total CO emissions for ethanol briquettes in Chitetezo Mbaula and Kenya Ceramic Jiko (KCJ) stoves weighed 3.089g and 1.7488g respectively. The mean CO emission rates are 0.050g/min in Chitetezo Mbaula and 0.029g/min in Kenya Ceramic Jiko as compared to the WHO (0.07g/min) benchmark (Figure 4.26). This show that there are reductions in CO emissions in ethanol briquettes. In Chitetezo Mbaula stove the percentage difference is 28.57% while in Kenya Ceramic Jiko the difference is 58.57%. These results show a wider gap away from the WHO benchmark especially when ethanol briquettes are burned in Kenya Ceramic Jiko stove.

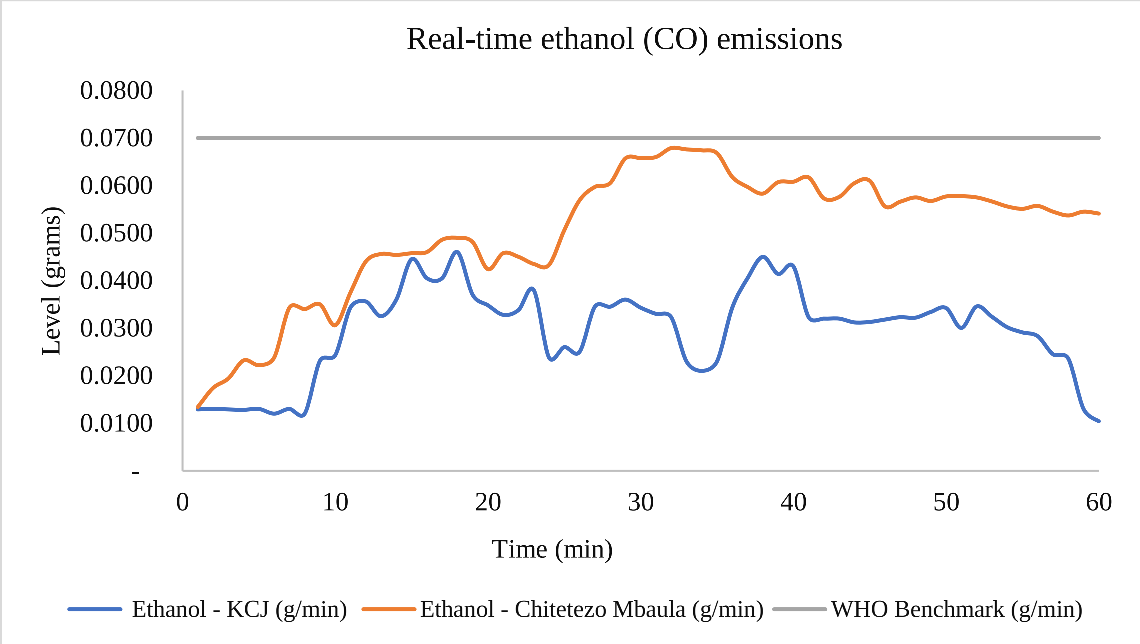
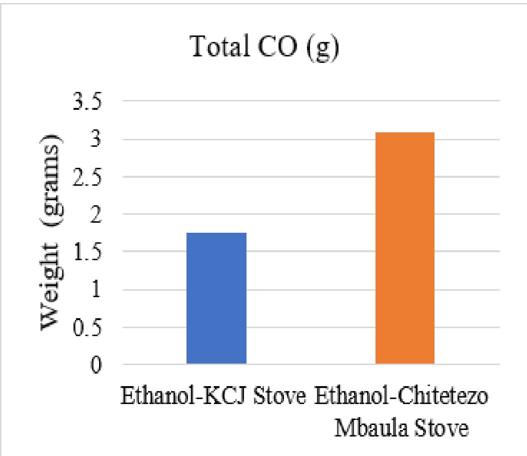


Figure 4.25 Real-time CO Emissions from Ethanol Briquettes

Source: Author,2022



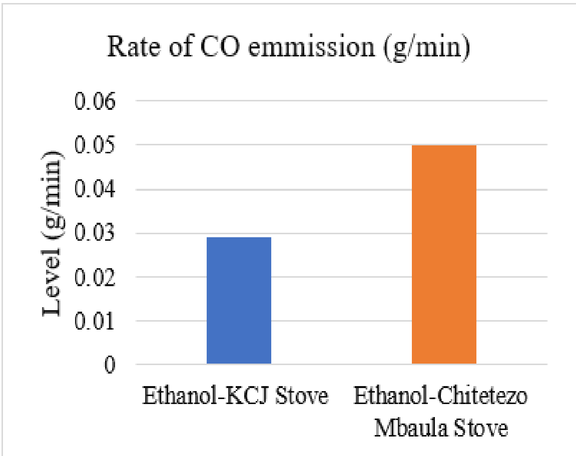


Figure 4.26 Total weight of captured CO and the rates of emission

Source: Author,2022

4.3.5.2 Particulate matter

The real-time trend of PM 2.5µm emission rate of Charcoal in Kenya Ceramic Jiko Stove was recorded for the period of an hour and it has been compared to the proposed WHO benchmark value of 1500mg/min as shown in Figure 4.27. The results show that total weight of particulate matter 2.5µm emissions from charcoal in KCJ cook stove weighed 83,882.12mg. On average, the emissions were released at the rate of 1398.03mg/min which is below the benchmark value of 1500 mg/min (see Figure 4.28). The study has found that charcoal have relatively low emissions of particulate matter hence a reduction by 6.798 % away from the proposed benchmark.

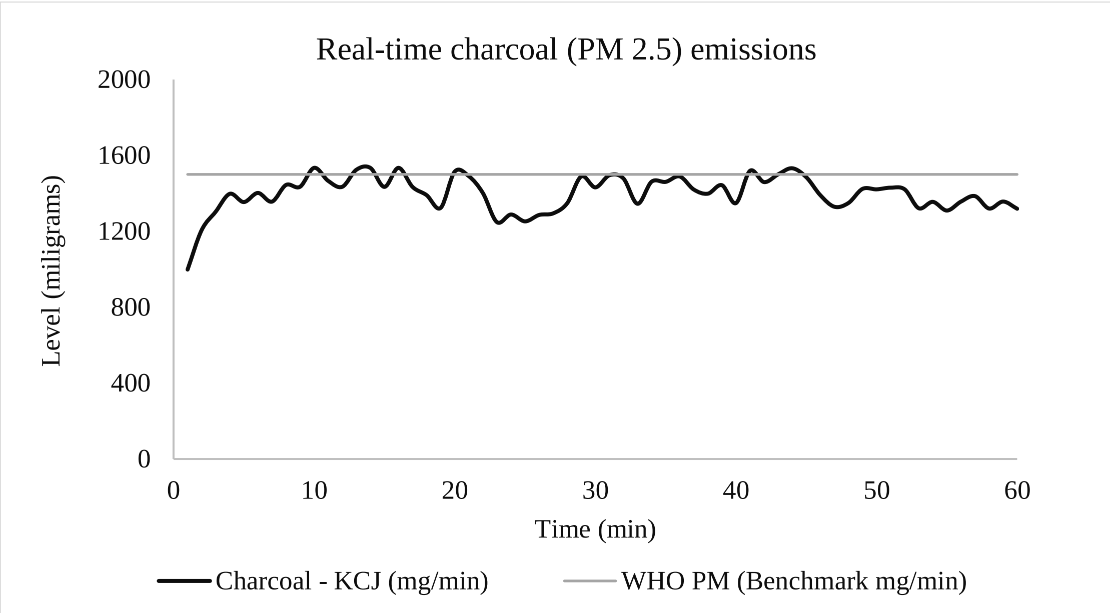


Figure 4.27 Real-time record of PM 2.5 emission from Charcoal in KCJ stove

Source: Author,2022

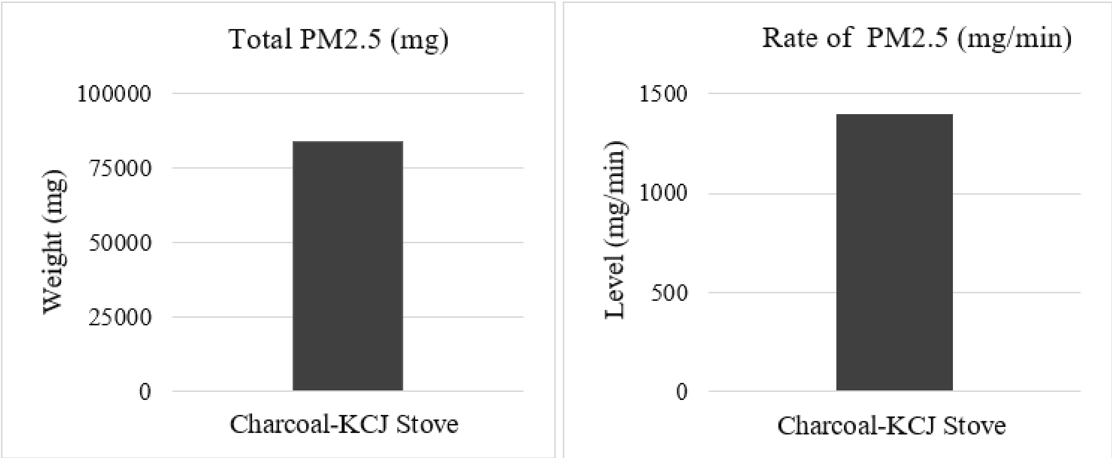


Figure 4.28 Total captured PM2.5 from charcoal KCJ stove and their rate of emission.

Source: Author,2022

Figure 4.29 shows the real-time record of PM 2.5 emissions from ethanol briquettes in Kenya Ceramic Jiko and Chitetezo Mbaula stoves. The trends of indoor air pollutants (PM2.5) are compared to a WHO proposed benchmark value of 0.15 mg/min.

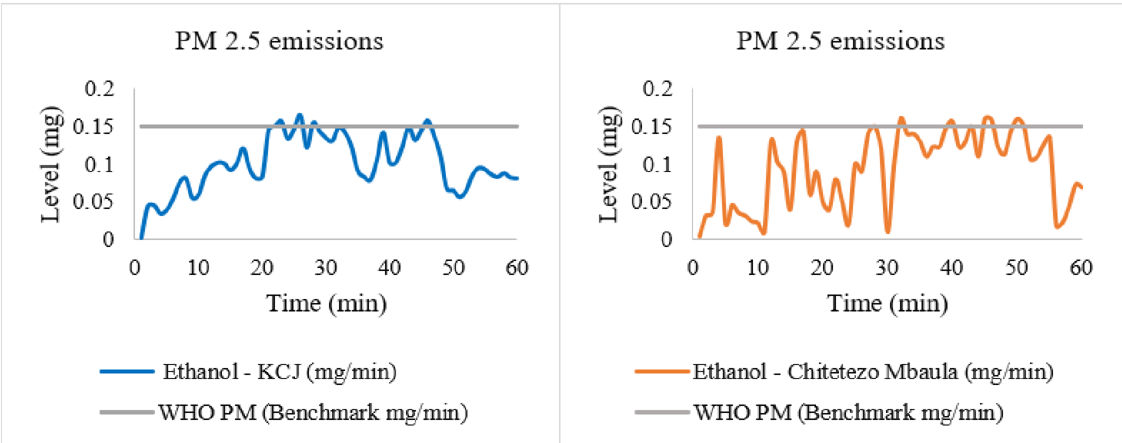


Figure 4.29 Real-time trends of PM 2.5 emissions from ethanol briquettes stoves

Source: Author,2022

As presented in Figure 4.30 the total weight of PM 2.5 µm emitted from ethanol briquettes in Kenya Ceramic Jiko and Chitetezo Mbaula cook stoves weighed 5.588 mg and 6.052 mg respectively. On average PM2.5 were released at the rate of 0.0931mg/min in KCJ stove and 0.1009mg/min which are below the benchmark value of 0.15 mg/min. The percentage difference shows that there is a big gap between actual tests and the proposed WHO benchmark. The results show that Ethanol briquettes have relatively low PM emissions hence a reduction by 37.93% and 32.73% away from the proposed benchmark in KCJ and Chitetezo Mbaula Stoves respectively.

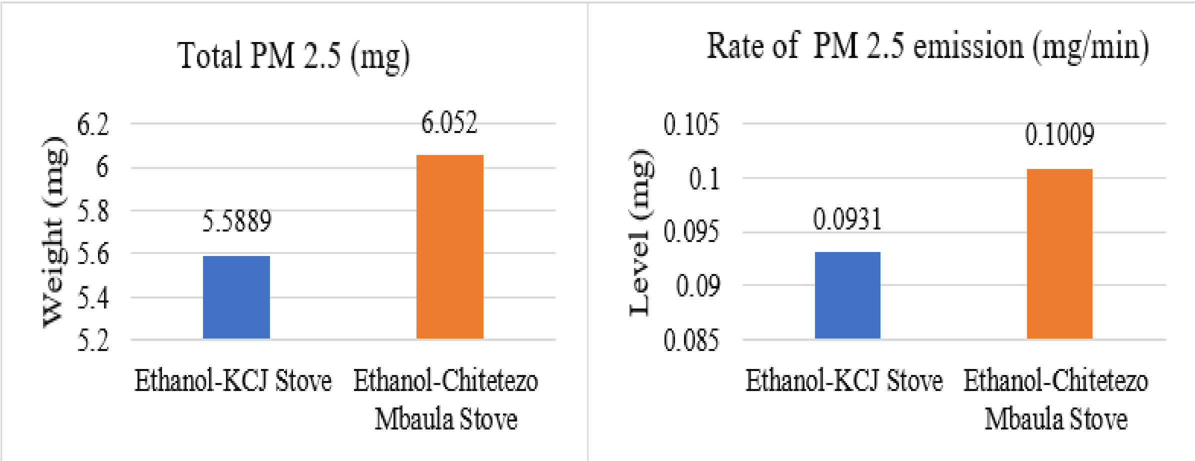


Figure 4.30 Total captured PM2.5 from ethanol briquettes in KCJ and Chitetezo Mbaula stoves and their rate of emission

Source: Author,2022

4.3.6 Evaluating the performance of ethanol briquettes fuel

This study compared the designs of combustion chambers for burning ethanol briquettes in modified stoves, as well as their efficiency, performance and emissions against charcoal stove models. Research studies have illustrated that calorific values are used to determine the efficiency of cookstoves (Fakinle *et al.*, 2019). The high energy content in ethanol briquettes gives high thermal efficiency for both Kenya ceramic Jiko and Chitetezo Mbaula hence the ability to cook or boil water faster than charcoal which has low energy content. Ethanol briquettes not only have high gross (High Heating Value) and net (Low Heating Value) energy content per kilogram but also have low carbon content than charcoal fuel. Cooking with ethanol briquettes would emit less carbon into the atmosphere than charcoal. The moisture content for ethanol briquettes is in an allowable range of 15 to 20% as reported from previous studies (Oketch *et al.,* 2014). The comparative analysis of water boiling tests indicates that the overall time taken to boil water or cook food is faster when Chitetezo Mbaula is used followed by Kenya ceramic Jiko while the charcoal in the KCJ stove was very slow. The study has also found that the time taken to boil or cook when a lid is on or off the pot is not statistically significant at a 95% confidence level in all the tests.

Besides, the results on specific fuel consumption for ethanol briquettes stoves show that Kenya ceramic Jiko stove saves more ethanol briquettes than Chitetezo Mbaula. Fuel comparisons show that the use of ethanol briquettes saves more energy for cooking than charcoal. Coefficient of Variation (CoV) is a ratio of standard deviation to the mean(Faxälv, 2007). Higher values of coefficient of variation shows a great dispersion around the mean value while low values indicate precise estimates of the test parameter. Studies (WBT Technical Committee, 2013) have reported parameters with benchmark values equal to 25% or less are precise estimates hence no need to conduct further tests to increase confidence such a parameter at 95% interval.

Therefore, the findings from water boiling tests, show low/small coefficients of variations in the time to boil, and stove characteristics such as burning rate and firepower in all tests with treatments either lid on or lid off. The CCTs findings also show low variations in the total weight of food cooked, specific fuel consumption in g/kg, and the total cooking time (min). In this study, it is found that in all the three stove tests thermal efficiencies increase when the specific fuel consumption decrease and these findings correspond to previous studies (Boafo-Mensah *et al.,* 2013; Fakinle *et al.,* 2019). Overall, the study has confirmed that there is a reduction of carbon monoxide and particulate matter emission. Also, there is high stove efficiency and performance when ethanol briquettes are used for cooking.

4.4 The impacts of social-cultural factors on the adoption of ethanol briquettes

In the study, households were given ethanol briquettes to use for three weeks. To address the second objective of the study, data were collected to understand social-cultural users' perceptions or experience of the fuel to determine how it might fit into the cooking mix and the potential for adoption and sustained use at large scale. The results are presented and discussed in the subsequent sections.

4.4.1 User experience and perceptions

As shown in Figure 4.31, participants used ethanol briquettes for cooking. In the focus groups, users said that they liked and preferred to use ethanol briquettes together with the stoves because of non-dirtiness and non-toxicity. Besides, igniting the fuel was very easy and caught light quickly. These results are in tandem with what Putti *et al* (2015) mentioned that technical benefits encourage consumers to accept, adopt and certainly pay for modern fuels. However, the duration for a briquette to finish burning depends on the size. The larger the size of the briquette the longer it took to burn and vice versa.

Figure 4.31 Participants cooking food using ethanol briquettes

Source: Author,2022

4.4.2 Cooking diaries

Figure 4.32 shows the fuel and stove use trends derived from cooking diaries data. The results show that household frequency of using ethanol briquettes was high, though the frequency fell over the first four days of each week (21,22,23 and 24 December), and this trend was somewhat similar for the entire period. Ethanol Briquettes use increased slightly on day six and finally decreased on day seven. The study assumed that the use pattern was somewhat related to the amount of fuel provided, with high use soon after fuel was provided, which then fell with consumption over the week. The use patterns showed that households were still using charcoal, firewood and other traditional fuels. Multiple-use occurred because households preferred to cook different meals with different stove types.

The adoption of ethanol briquettes into the cooking mix was somewhat complex because households preferred to cook some meals with the existing fuels despite having access to modern fuel. It was also observed that some households were saving the fuel for later use towards the end of a week rather than using it all at the beginning of the week. However, it was interesting to observe that the use of ethanol briquettes for some days was above the existing cooking fuels.

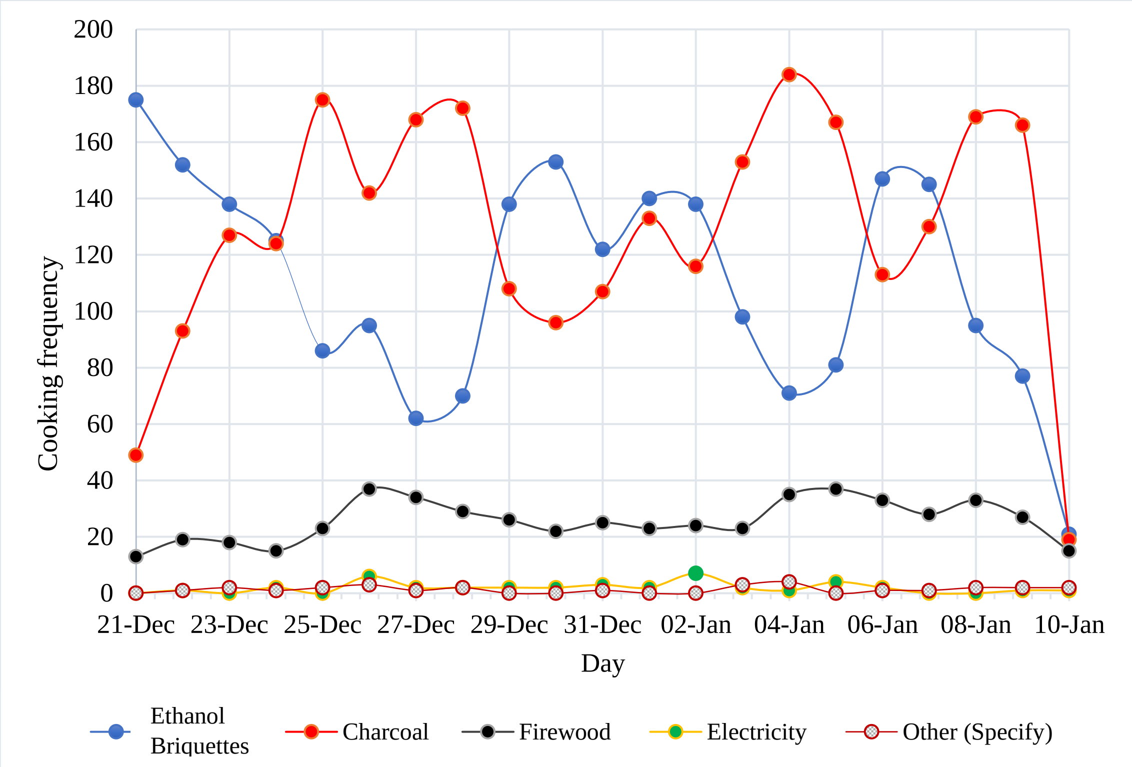


Figure 4.32 Household cooking frequency and fuel use patterns.

Source: Author,2022

The results in Figure 4.33 show that charcoal was used slightly more often than Ethanol Briquettes and other alternatives. The study through the cooking diaries found that the overall fuel use frequency of ethanol briquettes was 41.59%, charcoal 48.35%, firewood 9.61%, electricity 0.71% and other specified fuels 0.49%. The study found that households although stacked the fuels, they preferred to use ethanol briquettes more despite that the fuel was selective when cooking on some types of food.

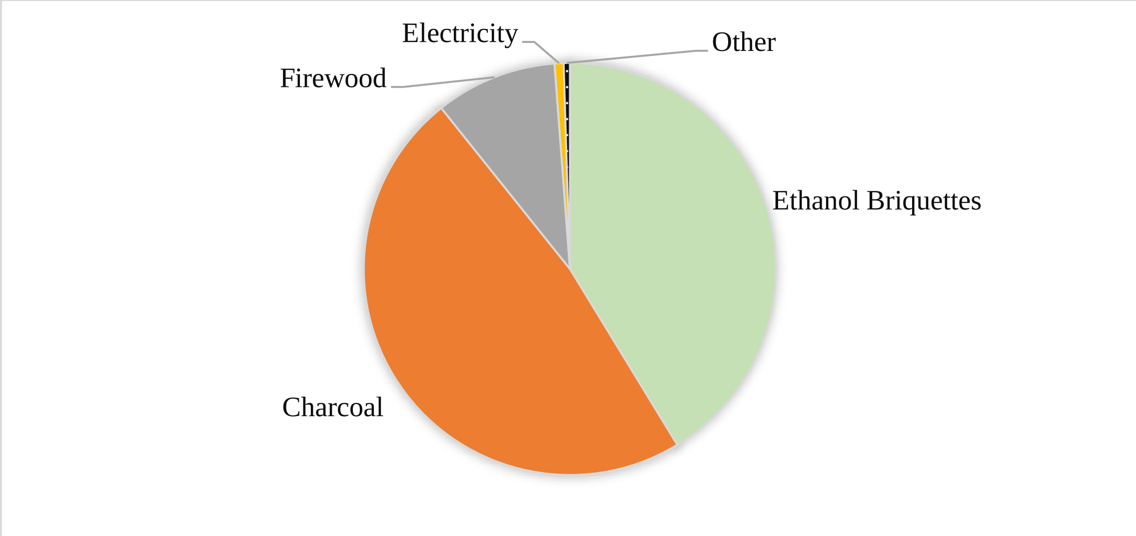


Figure 4.33 Overall percentage use of cooking fuels

Source: Author,2022

The stove use patterns and the overall percentages in this study show the extent of the adoption of different fuels by participants. In general, the findings indicate that households prefer using multiple fuels for cooking. A study in Malawi (Concern Universal, 2011) found similar results that after commissioning improved cookstoves, households continued to use their existing fuels and stoves in a practice called fuel stacking. The reasons for stacking may be associated with social-cultural aspects like taste preferences, cooking practices, local cuisine, kitchen type, and cultural add-ons (Atanassov, 2010; Risseeuw, 2012). Additional studies in countries such as Tanzania (Choumert et al., 2017), Zambia (Tembo *et al.*, 2015), Mozambique (Risseeuw, 2012), and Nepal (Rogers, 2020) among others, similarly found stacking behaviour of consumers rather than switching.

Stacking behaviours are amplified when consumers have a wide range of choices on what to cook, when, and using what device and fuel. Studies in Pakistan (Rahut *et al.*, 2020), Guatemala (Heltberg, 2005) and Mexico (Riuz-Mercado, 2012; Ruiz-Mercado *et al.*,

2011) have discussed that when households have many sources of cooking energy, stacking usually occur. In the present empirical study, stacking practice was observed when participants were given ethanol fuel each week because they had several cooking fuels options.

4.4.3 How ethanol briquettes were used for cooking

Figure 4.34 shows that 53 participants were able to use ethanol briquettes weighing 1.7 Kgs was for some days depending on what they usually cooked. Results from the household interviews indicate that the majority percentage of households would use 1.7 Kgs of fuel between three to five days if they had to cook with briquettes only following their daily normal cooking habits. The results show that 24% of the households used the fuel for a maximum of 3 days, 31.48% used it for 4 days while 25.93% for 5 days in a week, 5.56% for 6 days and lastly 12.96% for 7 days.

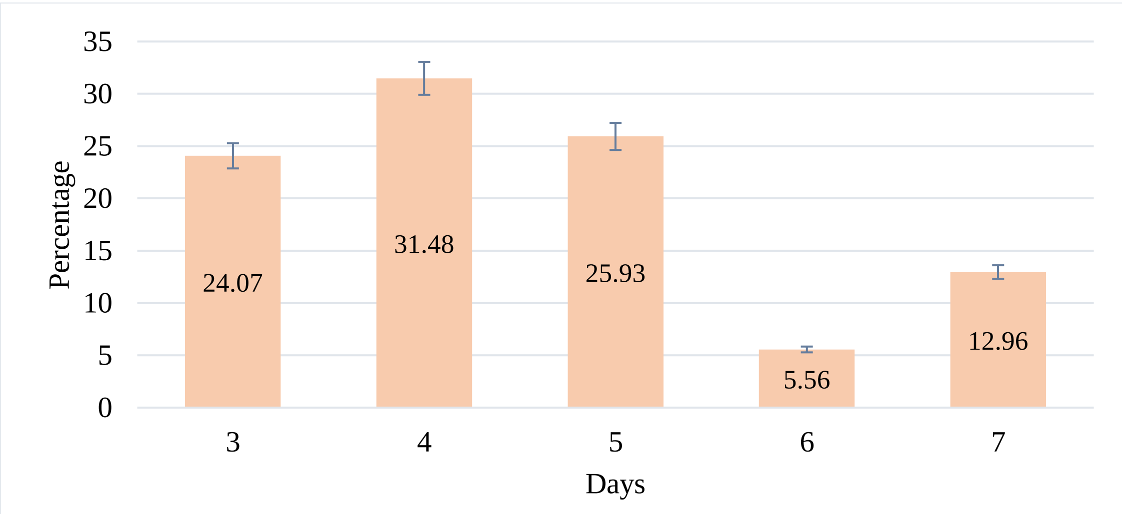


Figure 4.34 Weekly cooking using 1.7 Kgs of ethanol briquettes

Source: Author,2022

The eating habits contributed to the amount of fuel used in the study. In some cases, households were cooking their meals once a day and others had a habit of cooking 3 to 4 times a day. This aligns with a study in Rwanda (Kanangire *et al.*, 2016) which discussed that families that cook more time than the other, use more fuel within a short time. This result in more money used on purchasing cooking fuels. The type of food and cooking fuel suitability scrutiny was done to establish what dishes would be inappropriate to be cooked using ethanol briquettes.

The focus group results showed cooking all types of food except African cake, and braai meat are suitable with the ethanol briquettes fuel and the cookstoves. Modern stoves/fuels that are compatible with most dishes are likely to be adopted and used. It is significant to recognise that households always chose to use cooking fuels and stoves that are compatible with raw food or items intended to be cooked or heated. The results are in tandem with the study findings of Gould and Urpelainen (2018) which revealed that fuels and stoves that do not meet the needs users are unlikely to be adopted.

4.4.4 Benefits of ethanol briquettes and cookstoves

Participants reported that all the stoves using ethanol briquettes provide social, health and environmental benefits. As shown in Figure 4.35 the fuel and stoves are easy to use and safe for cooking. Due to the cleanness of the cooking fuel/devices, there were no illnesses such as headaches, eye irritations, and skin burns when handling the fuel. In focus group discussions, participants said that the fuel and stoves are modern, efficient and sustainable for household cooking. The study overall has found that the combination of fuel and cookstoves are the cleanest, least smokey, fastest and easiest when used for cooking, safe and performs well. These benefits were also discussed in other studies (BCB International, 2015). The study participants were quick to mention that the fuel/stove combinations were their desirable option for cooking and should be prioritized among the clean cooking energy sources in Malawi.

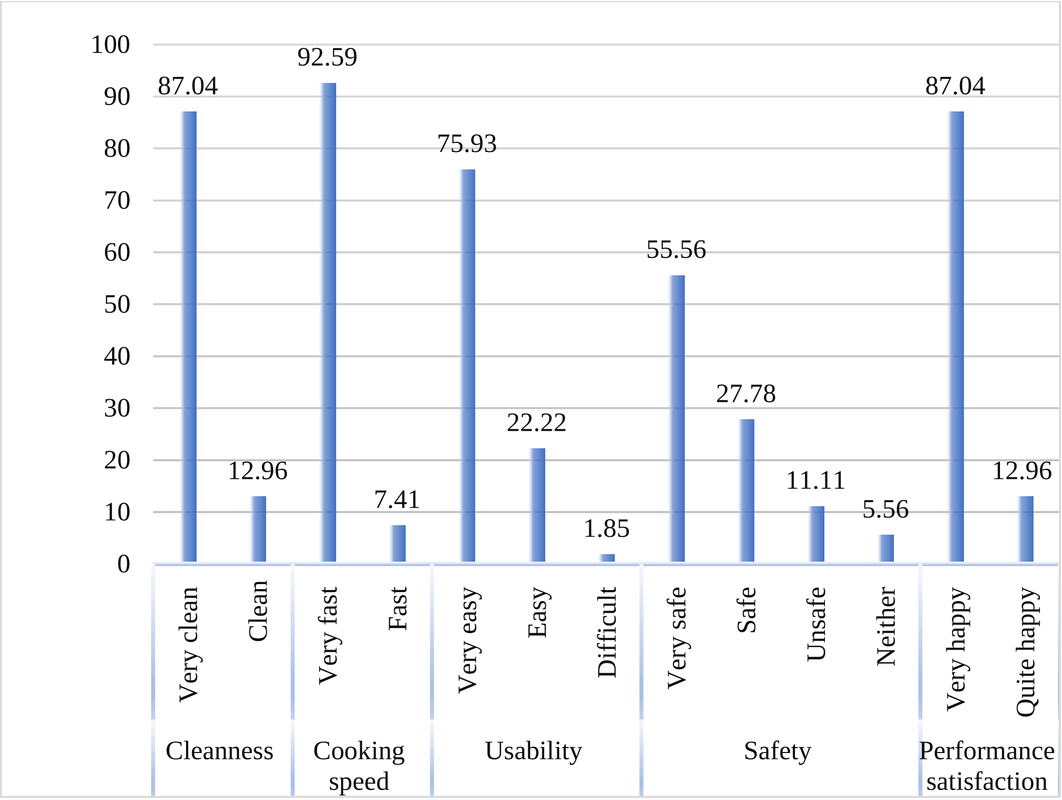


Figure 4.35 Benefits of cooking using ethanol briquettes and cookstoves

Source: Author,2022

4.4.5 Challenges encountered during use of ethanol briquettes fuel and cookstoves

The study participants reported some challenges they encountered during the stove and fuel implementation period. Despite having difficulties learning and familiarizing themselves with how and when to replenish the combustion chamber with a briquette, participants reported that the flame went off often when the fuel completed burning without immediate refill thereby increasing the time taken to cook. The cooking task required the cook to do frequent fuel checks and replenishment, hence the study found that it is difficult to cook and do other household chores simultaneously.

Besides, it was found that fume was emitted from the combustion chamber because of the residues that accumulated in the containers. An increase in room temperature and poor storage conditions of ethanol briquettes contributed to melting. Moreover, shrinkage was observed when the fuel was left uncovered for a few minutes due to evaporation. The participants also observed that the size of stoves and combustion chambers could not suit bigger kitchenware. The cookstoves design does not match or support the use of big size pots or utensils. These incompatibilities prohibit households from using the stove when they want to cook in bulky quantities.

Focus Group discussion results found that the Chitetezo Mbaula stove needed a redesign to prevent smoke, by facilitating complete combustion and reducing flame overflow round pot exteriors. It was, therefore, suggested that the size of the stove opening be minimized to regulate air inflow and circulation. Again, both stoves should have a sliding plate that should be used for refilling a briquette by pushing inside the combustion container. Air spaces, inside Chitetezo Mbaula, should also be minimized. Finally, the study attests that ethanol briquettes fuel must be stored in cool dry place and away from firelighter or match.

4.5 Economic determinants

4.5.1 Initial costs of cookstoves and combustion chambers

The production cost for chambers by local tinsmiths ranges from MK500 to MK1000 (USD 0.7 - USD 1.3). Therefore, the initial costs of improved cookstoves Kenyan Ceramic Jiko and Chitetezo Mbaula and the combustion chamber MK2,300 ($.2.89) and MK2,000 ($2.52) respectively. According to a webinar by the Clean Cooking Alliance, Mussa, Alemu & Zeleke (2020) reveals that the maximum retail price of Chitetezo

Mbaula on the market is MK1,500 ($1.89) and the cost is even lower at the production site. The Kenya Ceramic Jiko stove is priced at MK1,700 ($2.14) on the market (Mussa *et al.,* 2020). The study has found that the prices of cooking devices matter and that the initial costs of stoves with inserts are relatively cheap. In this regard, the affordability of existing cookstoves and combustion chambers eliminates the barrier of adoption that might be associated with the high initial costs of cooking devices.

4.5.2 Ability and willingness to purchase cooking fuels

The focus group discussions revealed that based on the economic viewpoint, most of the participants would prefer not to use ethanol briquettes for cooking if a 5kg bucket of fuel is costing them MK5,000 to purchase due to financial hardships. The study found the participants would be willing to pay MK 3,500 for ethanol briquettes.

In Haiti (Sagbo, 2014), consumers also responded similarly that they would be willing to buy the fuel for a price not exorbitant. Study participants suggested that ethanol briquettes should be packed in different weight categories with a range of prices so that people should have a wider preference. Furthermore, it was noted that if the fuel could be purchased in different quantities, it would replicate the existing practice of charcoal users of buying packages in quantities of their choice. This shall make it easier for households to pay for fuel depending on their available income.

In Figure 4.36 respondents were asked to choose the type of fuel they would buy in a large quantity than the other given the same price of biomass fuels like charcoal/firewood and ethanol briquettes. The study has found that more than half of the participants 51.85% would buy ethanol briquettes only while 45.3% would purchase mostly ethanol briquettes and little biomass fuels. At least 1.8% would prefer to buy both fuels in equal quantity while 1.05% would prefer to buy more charcoal/firewood and fewer ethanol briquettes.

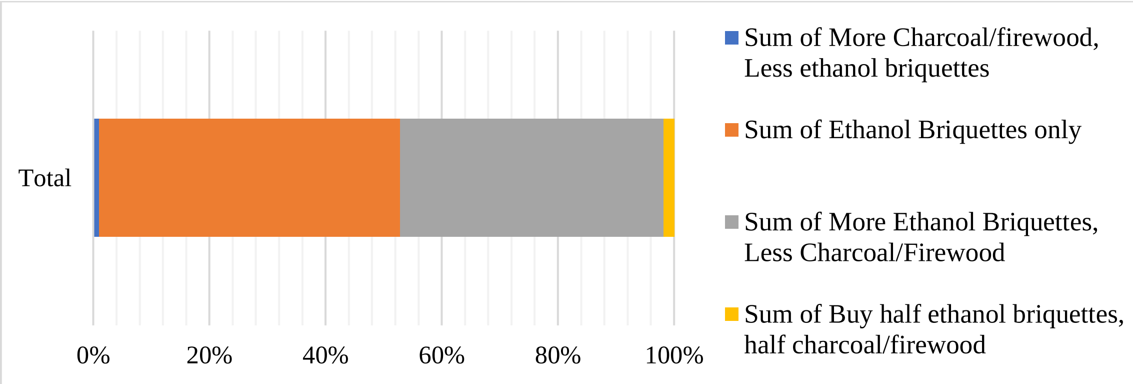


Figure 4.36 Willingness to purchase cooking fuels

Source: Author,2022

A study in Haiti by Sagbo (2014) found out that willingness to pay depends on the type of fuel itself, income levels of the consumers and the market price. In Kenya (CCAK, 2019) the willingness to pay for ethanol fuel is influenced by the market price. When ethanol price increases, fewer people purchase the fuel. The relationship between fuel stacking behaviour and willingness to pay (WTP), and the household characteristics associated with fuel stacking behaviour. The analyses showed that stacking does not affect WTP (Rogers, 2020).

4.5.3 Estimation of the costs of fuels

4.5.3.1 Costs of ethanol briquettes

Table 4.9 below indicates different cost scenarios for ethanol briquettes based on High, Medium and Low prices. The suggested cost of MWK 3500 is provided as a benchmark since it is what the study participants would be happy to pay for 5 kg. As a starting point, the report references ethanol prices in Nairobi and Dar es Salaam (\$0.7 – 0.73/litre), then a margin was added to arrive at an estimated price in Malawi of $1/litre (excl, VAT). Finally, +/- 20% was factored in to arrive at the low and high-cost scenarios.

Table 4.9: Estimating the price of ethanol briquettes using cost scenarios

Cost Scenario	Ethanol Briquettes (MK/kg)	Cost per 5kg
High Cost	MWK 912	MWK 4,560
Medium Cost	MWK 760	MWK 3,800
Low Cost	MWK 608	MWK 3,040
Suggested Cost	MWK 700	MWK 3,500

Source: Author,2022

The findings reveal that the medium cost scenario although is slightly higher (an extra of MK300 to pay for a 5kg bucket) but is very close to the “suggested Cost” of ethanol briquettes that study participants made during the Focus Group Discussions. Interestingly, the high-cost scenario is close to the price that ethanol briquettes retails at in the UK (BCB International, 2015). The findings further illustrate that the low-cost scenario although is below (a deficit of MK460 to buy a 5litre bucket) but is very close to the “suggested Cost” of ethanol briquettes that study participants are willing to pay. The best price for the fuel is MK760/kg or MK3800 for a bucket weighing 5kgs. This cost is affordable for the households, but if VAT will be included the cost would rise. Puzzolo (2013) also observed that tax on ethanol fuel may substantially increase ethanol price hence reducing the number of users.

4.5.3.2 Market prices of charcoal

The market assessment survey of charcoal (Appendix 3) revealed that the package mostly and often sold on the market is sack bag medium ($2\frac{1}{2}$ line). As shown in Table 4.10

charcoal prices of charcoal in the packages are expensive during the rainy season and cheaper in the dry season. Charcoal in each package was sorted to remove debris and weighed using a digital scale.

Table 4.10: Market prices of charcoal

Package	Season		Kgs before sorting	Kgs after sorting
	Rainy	Dry		
Plastic bags (very small)	150* – 200	150* – 200	0.56	0.56
Plastic bags (Medium)	250* – 300	200* – 250	0.85	0.85
5litres container	500* - 600	500* – 550	3.01	2.86
10litres container	1300* – 1400	1250* – 1300	4.91	4.13
Sack bag medium (Flat)	5500* – 6,000	4,000* – 4,800	12.40	9.81
Sack bag medium ($1\frac{1}{2}$ line)	6,500*– 7,000	5,500* – 6,000	12.98	10.22
Sack bag medium ($2\frac{1}{2}$ line)	7,000* – 8,000	7,000* – 7,500	13.56	10.70
Sack bag (Mpala)	8,000*– 9,000	7500* – 8000	17.04	13.87
Sack bag large (3 line)	14,500* –15,000	9,000*– 11,000	19.13	15.08
Sack bag Extra-large (Mbwindi/Mbeya	22,000* –23,000	15,000*–18,000	24.88	18.96
Sack bag with extension (Chumuni)	12,000* –13,500	10,000* –12,500	21.08	16.99

**Last price offer after bargaining.*

Source: Author,2022

4.5.4 Comparative costs of cooking using charcoal and ethanol briquettes

The results in Table 4.11 were calculated based on data from Tables 4.6 and 4.10. The weight of ethanol briquettes and charcoal fuels used and the specific fuel consumptions of each stove were used to calculate the cost of cooking. The medium cost scenario of ethanol briquettes at MK 760 /Kg was used. A medium-size bag weighing 10.7 kgs of usable charcoal after sorting is the most often sold at Mk7,000. The results show that the cost of cooking using ethanol briquettes is cheaper MK344.28 or MK 670.32 when Kenya Ceramic Jiko stove is used.

Table 4.11: Cost of Cooking a meal

Stove/fuel	Fuel used (g)	SFC (g)	Cost based on SFC (MK)	Cost based on fuel used (MK)
Charcoal in Kenya Ceramic Jiko	1,300	652	426.54	850.46
Ethanol Briquettes in Kenya Ceramic Jiko	882	453	344.28	670.32
Ethanol Briquettes in Chitetezo Mbaula	929	477	362.52	706.04

Source: Author,2022

4.6 Testing the level of adoption for ethanol briquettes and cookstoves

The study has tested the level of adoption to evaluate whether ethanol briquettes and their paired stoves are a viable household cooking energy option. The study considered the technical, social and economic factors that might influence the adoption and use of the technology in Malawi.

4.6.1 Correlation analysis

The strength and association between the variables in Table 4.12 were determined by Pearson's coefficients of correlation. The measures of relationships follow a linear trend. If the value is equal to zero (x=0) it shows that there is no association between the two variables. Besides, values greater than zero (x >0) and less than zero (x<0) indicates a positive and negative association respectively. When the variable increases as a result of an increase in the value of the other variable, there is a positive association and vice versa. There is a medium-strength of correlation (-.355) between adoption and technical performance of the fuel and cookstoves but the direction of the relationship is negative.

Adoption decreases due to poor technical performance and efficiency and this is significant (.009) $p<0.05$ at a 95% confidence interval. However, the correlation is significant at $p>0.01$ at a 99% confidence interval. There is a small correlation between variables of adoption and social-cultural factors (.266) with a p-value of .054 which is not significant. This means that adoption increases when social-cultural factors such as awareness/sensitization, education levels, positive peer influence also increase. Besides, adoption is achievable when there is no cultural or religious resistance.

The variables of adoption and economic factors also show a small strength of correlation (.029) with a p-value of .837 which is not statically significant. In these two cases, the direction of correlation is positive and the p-value is greater than 0.05 level at a 95% confidence interval. Economic factors such as household income, affordability and low daily costs of cooking influence the adoption.

Table 4.12: Correlations and Coefficients

		Adoption	Technical - performance & efficiency	Social-cultural factors	Economic factors
Adoption	Pearson Correlation	1	-.355**	.266	.029
	Sig. (2-tailed)		.009	.054	.837
Technical performance and efficiency	Pearson Correlation	-.355**	1	-.266	-.106
	Sig. (2-tailed)	.009		.055	.450
Social-cultural factors	Pearson Correlation	.266	-.266	1	-.086
	Sig. (2-tailed)	.054	.055		.543
Economic factors	Pearson Correlation	.029	-.106	-.086	1
	Sig. (2-tailed)	.837	.450	.543	

***. Correlation is significant at the 0.01 level (2-tailed).*

Source: Author,2022

4.6.2 Regression analysis

The results in Table 4.13 show that the predictors for the adoption of ethanol briquettes and cookstoves in this study have a positive influence on adoption (R=.397). All the factors have contributed to adoption by 15.8%. The Analysis of Variance (ANOVA) test the hypothesis that multiple R in the model equals 0. The statistics show that the model reaches statistical significance (sig. = 0.037).

Table 4.13: Regression model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.397[a]	.158	.106	.323	.158	3.063	3	49	.037

Source: Author,2022

In Table 4.14 below the linear regression was used to determine how the determinants impacted the adoption of biomass stoves.

$$Y = 1.225 - 0.112x + 0.44x + 0.007x + \varepsilon$$

Based on the results of standardized coefficients beta (β= -.304), t-value (t= -2.216) and Sig. (p= .031), the study has found that the technical performance and efficiency of ethanol briquettes cookstoves have a strong influence or contribution on adoption. This is followed by the social-cultural factors (β= .186), which are positive such as high education level and knowledge, awareness and sensitization, encouraging peer influence among others. The t-value (t= 1.361) and Sig. (p= .180). Finally, the contribution of economic factors (β= .013) which are favourable such as high household income, affordable and low daily costs of cooking influence adoption. The t-value (t= .096) and Sig. (p= .924).

Table 4.14: Regression Analysis showing the influence of each determinant on adoption

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.225	.218		5.616	.000
	Technical performance and efficiency	-.112	.050	-.304	-2.216	.031
	Social-cultural factors	.044	.033	.186	1.361	.180
	Economic factors	.007	.073	.013	.096	.924

Source: Author,2022

4.6.3 Testing the Hypothesis

The study tested the study hypotheses based on the decision rule: reject the null hypothesis if $p<0.05$ and accept the null hypothesis if $p>0.05$. The results are given in Table 4.15 below.

Table 4.15: Hypothetical analysis of factors that contribute to the adoption

	Hypotheses	t-value	p-value	Decision
1	**H_0:** The poor technical performance and efficiency of ethanol briquettes and cookstoves do not significantly affect the household's decision of adoption **H_1:** The poor technical performance and efficiency of ethanol briquettes and cookstoves significantly affect the household's decision of adoption.	-2.216	0.031	Reject the null hypothesis $p<0.05$
	H_0: Positive social-cultural factors do not significantly affect the household's decision on the adoption and use of cooking fuel **H_1:** Positive social-cultural factors significantly affect the household's decision on the adoption and use of cooking fuel	1.361	0.180	Accept the null hypothesis $p>0.05$
3	**H_0:** Favorable economic factors do not significantly affect a household's choice of adoption and use of fuel and cookstoves. **H_1:** Favorable economic factors significantly affect a household's choice of adoption and use of fuel and cookstoves.	0.096	0.924	Accept the null hypothesis $p>0.05$

Source: Author,2022

Firstly, technical aspects such as efficiency and performance of fuel and cookstoves influence its adoption. In this study, households adopted the fuel and cookstoves because the innovation has the capacity of promoting efficient cooking. Besides cooking was more convenient, they observed health benefits due to reduced household air pollution.

Secondly, social-cultural factors such as high education levels of household heads are very essential when it comes to the adoption of modern technologies. Since household heads are the ones who make decisions on what fuel to use, a lack of proper knowledge and understanding of the benefits of using modern fuels would make them not adopt the fuel. Positive peer influence describing the cleanliness, affordability, and efficiency of the cookstove system encouraged adoption and use (Seguin *et al.*, 2018). Cultural beliefs and cooking habits encouraged fuel stacking hence influencing adoption negatively. Awareness and sensitization campaigns on new cooking technologies have promoted the adoption and use of ethanol briquettes by households (Gould & Urpelainen, 2018).

The economic factors such as income or wealth status of households is an insufficient determinant for adoption. In this study, households cooked using multiple fuels despite being given free fuel. In the context of this research, the results showed fuel stacking as feasible and fully applicable in reality.

4.7 Chapter summary

This chapter has presented, interpreted and discussed the study results. Results of the pilot survey show that most households have 6 people and their normal monthly income level is 150 thousand, highest level is 200 thousand and lowest level is 50 thousand Malawi Kwacha. The households belong to low-middle income status. The study found that 58 percent of the households have no access to electricity. The study reveal that households spend about MK7,000 and MK 15,000 monthly to buy firewood and charcoal for cooking. The technical performance show that Chitetezo Mbaula stove is faster but it consumes more ethanol briquettes when boiling 1 litre of water while Kenya Ceramic Jiko is slow and it use less fuel. Ethanol Briquettes have high Calorific Values and they release extreme heating values which contribute to high stove efficiency than charcoal fuel. Emissions below WHO benchmarks are reported for ethanol briquettes.

The results from cooking diaries show that the use of ethanol briquettes was high but households preferred to use multiple fuels “Energy stacking” despite having adequate ethanol briquettes for cooking. Energy stacking occur because households prefer to cook multiple dishes simultaneously to save time. When ethanol briquettes are priced MK760 per Kg it is cheaper by 21% to cook a meal using Kenya Ceramic Jiko stove and 17% cheaper in Chitetezo Mbaula. The economic cost of cooking with ethanol briquettes is low for a household using Kenya Ceramic Jiko because it consumes less fuel.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Chapter overview

This chapter concludes the study and presents its input to the existing body of knowledge about ethanol briquettes as a clean cooking fuel alternative in Malawi.

5.2 Conclusion of the study

This study has sought to understand the adoption and sustained use of ethanol briquettes for cooking in selected Areas in Malawi. The selected Areas were 36,44 and 49, all based in Lilongwe. The research established three objectives namely: (i) to assess the technical performance of ethanol briquettes and charcoal with different stove models to determine if existing models can be used with or without adaptations, (ii) to assess the social-cultural perceptions/experience of users to determine how the fuel and stoves fit into the cooking mix and the potential for adoption at large scale, and (iii) to determine the economic cost of cooking with the ethanol fuel for a typical household compared with charcoal. Accordingly, the following research questions were posed to address these research objectives: How can ethanol fuel be retrofitted and paired with existing low-cost cookstoves for household cooking? What are the technical, economic and social-cultural factors that would affect the decision to adopt the technology? What are the differences between cooking costs associated with ethanol briquettes and charcoal?

The study has provided a solution to the challenges faced with burning charcoal in Malawi through the design and construction of clean and efficient cooking technologies. The results attained within the scope of this study have demonstrated that the energy content that ethanol briquettes can release is very high than charcoal which made it burn efficiently when paired with existing low-cost stove models although each pair performed differently. Ethanol briquettes performed faster on Chitetezo Mbaula with high stove firepower but consumed more fuel and vice versa when paired with Kenyan Ceramic Jiko.

The successful designs and construction of combustion containers did not only burn ethanol briquettes faster but also in a clean, easy, efficient and environmentally friendly manner. In terms of user satisfaction, ethanol briquettes fulfilled the cooking needs of the households but they preferred to use multiple fuels "energy stacking" in their cooking tasks. Kenyan Ceramic Jiko stove appears to be the most suitable option to take forward because it is very clean, modern, cheaper, less polluting, and saves fuel. From the economic perspective, ethanol briquettes would be competitive on the market if sold at MWK 760 per kilogram. It can be concluded that the performance of ethanol briquettes achieved high user satisfaction than charcoal.

5.3 Recommendations

i. Policy recommendations

The Malawi Energy Regulatory Authority should regulate the price of ethanol briquettes. The price is affordable at MWK 760/Kg, which would be close to the indicative willingness to pay level. As households are very price-sensitive, manufacturers should keep the cost of stoves and combustion containers as low as possible.

The cost of ethanol briquettes could be defrayed through grant funding for manufacturing equipment, as well as through carbon finance to subsidise ongoing fuel costs. Based on the willingness to pay customers, the required subsidy level should be assessed to see how it could be achieved.

ii. Technical recommendations

Local stove manufacturers and tinsmiths should be engaged and taught how to fabricate combustion containers. The designs and specifications in this study should be followed at all times. Kenyan Ceramic Jiko and Chitetezo Mbaula are the most widely available cookstoves in Malawi, and therefore, presents the primary opportunity to integrate with ethanol briquettes.

Possible modifications on combustion chambers should be prioritised in future to lessen emissions and enhance efficacy. In the Chitetezo Mbaula, the insert needs to be raised on legs and the insert needs to be longer to direct the flame to the bottom of the pot. For the Kenyan Ceramic Jiko, the main consideration is that the insert needs to be wide enough to give the fuel space to burn, but not so wide that it blocks the air vents in the bottom of the stove. In both cases the inserts need to have holes in them, starting halfway up to allow ventilation, without fuel spilling out as it melts.

iii. Operational recommendations

Training and capacity building should be done to promote the stoves and fuel. The public demand would increase when there is exhibition through different media, market demonstrations and showcase tours. Seminars and workshops should be done to educate the targeted groups on the benefits of using ethanol briquettes for cooking.

Ethanol briquettes should be made available to the public for use in different quantities for households to choose what they can afford to buy. Smaller quantities would make the fuel much more accessible as it replicates the purchasing behaviour of charcoal.

Stove and fuel awareness should be raised especially in Malawi through the existing village or urban development committees and other groupings. Therefore, significant work needs to be done to create awareness and change behaviours to enhance the adoption and use of ethanol briquettes.

5.4 Study Limitations

The major limitation in the study is the prevalence of the Covid-19 pandemic and the restrictions that affected the data collection task. The study analysed few emission parameters (CO and Particulate Matter) because other instruments at MBS were not calibrated. Furthermore, ethanol briquettes were few and cookstoves available for distribution only served 53 sampled households. A good study should have covered a wider sample for the reliability of results and to avoid bias.

5.5 Suggestions for Further Research

Future research should focus on the assessment of emissions such as black carbon, elemental carbon, organic carbon, nitrous and sulphur oxides and volatile organic carbons.

5.6 Chapter Summary

This chapter has outlined the conclusion, recommendations and suggested areas for further studies. The study also concludes that ethanol briquettes are a viable and sustainable source of energy for cooking in Malawi since it has high energy content, it burns efficiently, less polluting and satisfies the user needs. The study has suggested policy, operation and technical recommendations to enhance mass production, accessibility and availability of ethanol briquettes and stoves for widespread adoption.

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APPENDICES

Appendix 1: Assessment of Indoor Air Quality

CARBON MONOXIDE (CO)			PARTICUATE MATTER (2.5µm)		
Charcoal - KCJ (g/min)	Ethanol - KCJ (g/min)	Ethanol - Chitetezo Mbaula (g/min)	Charcoal - KCJ (mg/min)	Ethanol - KCJ (mg/min)	Ethanol - Chitetezo Mbaula (mg/min)
14.5	0.0129	0.0134	998.43	0.002	0.0045
20.6	0.0130	0.0174	1206.12	0.044	0.032
21.2	0.0129	0.0194	1303.34	0.045	0.0356
21.4	0.0128	0.0232	1397.65	0.034	0.135
20.6	0.0130	0.0222	1354.15	0.039	0.022
20.7	0.0120	0.0238	1402.34	0.054	0.0455
19.2	0.0130	0.0343	1356.49	0.075	0.0356
19.1	0.0120	0.0340	1444.36	0.081	0.032
21.8	0.0231	0.0350	1434.87	0.055	0.0245
24.1	0.0243	0.0306	1534.56	0.059	0.022
24.1	0.0343	0.0375	1465.89	0.085	0.010
24.6	0.0356	0.0440	1434.56	0.097	0.130
24.2	0.0325	0.0456	1524.11	0.102	0.102
22.3	0.0360	0.0454	1534.31	0.101	0.090
22.4	0.0445	0.0458	1434.24	0.092	0.040
23.5	0.0405	0.0460	1534.56	0.101	0.130
24.6	0.0405	0.0486	1434.05	0.121	0.143
22.3	0.0460	0.0490	1390.59	0.094	0.061
20.1	0.0370	0.0481	1323.56	0.081	0.090
20.4	0.0348	0.0424	1514.61	0.083	0.051
20.4	0.0328	0.0458	1490.79	0.146	0.040
21.2	0.0338	0.0450	1402.01	0.151	0.081

21.2	0.0380	0.0435	1248.56	0.157	0.050
21.4	0.0238	0.0433	1288.58	0.134	0.020
21.3	0.0260	0.0506	1252.45	0.147	0.100
19.3	0.0250	0.0569	1286.15	0.165	0.090
20.1	0.0345	0.0597	1294.68	0.122	0.140
21.4	0.0345	0.0605	1348.12	0.155	0.150
20.2	0.0360	0.0657	1489.45	0.144	0.121
23.1	0.0343	0.0658	1431.62	0.135	0.010
22.3	0.0330	0.0660	1495.46	0.131	0.100
20.2	0.0323	0.0679	1478.39	0.149	0.162
20.3	0.0230	0.0676	1345.26	0.142	0.141
20.4	0.0210	0.0674	1461.45	0.124	0.142
20.1	0.0230	0.0668	1460.67	0.091	0.131
20.2	0.0343	0.0618	1489.35	0.083	0.111
21.1	0.0405	0.0597	1420.26	0.079	0.121
21.8	0.0450	0.0583	1398.32	0.105	0.120
21.1	0.0414	0.0607	1443.24	0.142	0.148
20.1	0.0430	0.0608	1348.65	0.102	0.156
20.0	0.0323	0.0617	1518.97	0.102	0.123
21.2	0.0320	0.0573	1459.53	0.123	0.130
21.2	0.0320	0.0576	1500.12	0.149	0.151
19.1	0.0312	0.0605	1532.33	0.132	0.110
19.1	0.0313	0.0610	1485.34	0.145	0.162
19.4	0.0318	0.0556	1390.45	0.158	0.159
18.9	0.0323	0.0566	1329.45	0.138	0.123
19.4	0.0322	0.0575	1349.34	0.111	0.113
20.2	0.0334	0.0568	1423.67	0.067	0.143
20.1	0.0342	0.0577	1421.33	0.065	0.160
19.2	0.0300	0.0578	1429.92	0.056	0.150
19.1	0.0346	0.0575	1421.12	0.064	0.107

18.1	0.0324	0.0567	1321.58	0.085	0.109
19.3	0.0302	0.0556	1355.37	0.095	0.125
21.1	0.0291	0.0551	1309.53	0.093	0.135
20.4	0.0283	0.0557	1356.46	0.086	0.018
19.8	0.0245	0.0545	1385.57	0.083	0.023
19.6	0.0236	0.0537	1320.01	0.088	0.045
19.4	0.0130	0.0545	1356.89	0.082	0.073
19.3	0.0104	0.0541	1318.89	0.081	0.069

Appendix 2: Cooking Diary Form

Dzina la khomo: ______________________ Tsiku: _____________________

DISH 1 || Chakudya choyamba	Zipangizo zomwemwagwilisa ntchito?	Zomwe zaphikidwa/kutenthesedwa?		Kutenthesedwa?
Nambala ya anthu	Nkhuni - pa mafuwa □	Madzi osamba □	Kachewere yophika □	Kuphika koyamba □
Akulu : ____________	Nkhuni - pa Mbaula yamakono □	Madzi a thiyi □	Kachewere yokazinga □	Kutenthesa □
Ana : ____________	Nkhuni - pa Mbaula youmba (yokhazikika malo amodzi) □	Mandasi □	Mazira wophika □	Kufutsa □
	Makala - Pa Mbaula ya yoika makala □	Thobwa □	Mazira wokazinga □	
Nthawi yoyamba kuphika	Makala - pa Mbaula youmba (yokhazikika malo amodzi) □	Nsima □	Nyama yophika □	
Nthawi ____:____	Mafuta a nyali □	Mpunga □	Nkhuku yophika □	
	Gasi □	Phala laufa □	Nsomba zaziwisi yophika □	
Nthawi yomaliza kuphika	Magetsi - Hoti puleti (yaingo'no) □	Phala lampunga □	Nsomba zaziwisi yokazinga □	**Kudya nthawi yanji?**
Nthawi ____:____	Magetsi - uvuni yaing'ono + hotipuleti □	Nyemba □	Nsomba zowuma yophika □	Palibe □
	Magetsi - Hoti pulate yokhala ndi uvuni (yaikulu) □	Ndiwo zamasamba □	Nthochi yophika □	Zotsala □
	Magesi - Chophikira Mphunga □	Soya pieces □	Chinangwa chophika □	Kufutsa □
Kazutsa (Chakudya cha mamawa) □	Magesi - Maikulowevi yotenthetsela/kuphikira zakudya □	Mawungu □	Mbatata yophika □	Kuphikuratu
Nkhomaliro (Chakudya cha masana) □	Magetsi - Ketulo □	Zimbwente □		nthawi yabwino □
Mgonero (Chakudya chausiku) □	Firedragon - kenyan ceramic jiko □	Chikonda moyo □		
Zakudya zotoleza/zowonjezera □	Firedragon - chitetezo mbaula □	Zina: ____________________		
	Zina (Longosolani): ____________________	____________________		

Appendix 3: Market assessment survey of charcoal.

Charcoal is the most common biomass fuel used for household cooking in Malawi. A market assessment of the charcoal business in Lilongwe has revealed that people get prompted to venture into selling charcoal because it is a high demand commodity that gives more proceeds within a short period. Charcoal selling is among viable sources of livelihood that is easy to do than selling perishable merchandise. Most charcoal sellers started the business after being convinced by existing friends that have stayed in the business for long and make profits.

Charcoal is a profitable business because of its high demand for domestic use. The turnover depends on the season and availability of the commodity on the market. In the rainy season (December to July), the profit is high due to product scarcity as compared to the dry season (August to November) where it is plenty. However, the business earnings are now greatly affected by laws enforced by the Government of Malawi of restricting, banning and confiscating charcoal. On average, a market vendor was able to sell 8 bags and 5 bags of charcoal per day on a normal basis, 15 bags and 10 bags of charcoal during market days in rain and dry seasons respectively. If the business did not go well 2 bags are sold despite the season.

The study found that in rare circumstances, an individual vendor could sell up to 60 bags of charcoal per day. A female vendor in the Mtandire market said *"I sell more than sixty bags of charcoal per day. This is made possible through home deliveries to clients. Also, the use of multiple agents in Mtandire and Mg'ona speeds up my sales."* Large scale vendors in study markets usually order their stock from Salima, Dedza, Nkhotakota districts. Normally the stock arrives after 2 weeks because of using unchartered routes which are difficult to pass using vehicles. The quantity of charcoal depends on one's capital, vehicle space, availability of transportation, and charcoal product. Ceteris paribus, one vehicle transport charcoal up to 180 bags of different vendors if produced in abundance to Lilongwe markets. Where charcoal production is low, vendors rely on other supplies from Mozambique Dedza to supplement the required stock to be sold on the market. When security in border and forest patrols are intensive, at least 30 to 40 bags can be successfully transported to Lilongwe. Small scale vendors of charcoal order for new stock either on a daily or weekly basis depending on completion of previous stock.

Item	**Response**	**n**	**Percentage**
The overall population of charcoal vendors (n)		15	100
	Large Scale	9	60
	Small Scale	6	40
Sex of respondent	Female	11	73.3
	Male	4	26.7
Charcoal selling places	Streets	3	20
	Local market	8	53.3
	House yard	3	20
	Other (Specify)	1	6.7
Charcoal preferences of customers			
	Cheap	4	26.7
Cost	Middle	9	60
	Expensive	2	13.3
	Small Size	5	33.3
Bag size often sold	Medium Size	7	46.7
	Large Size	2	13.3
	Extra-Large	1	6.7
	Medium	8	53.3
Wood weight	Heavy	7	47.7
Duration for finishing selling charcoal stock	Less than 2 days	1	6.7
	2 to 4 days	5	33.3
	5 to 7 days	8	53.3
	More than 7 days	1	6.7
Frequency to have new stock	Daily	1	6.7
	Weekly	4	26.7
	Fortnight (2 weeks)	10	66.
Do not post-process charcoal to remove debris		15	100

Artificial/exotic trees are now used to produce charcoal due to the insufficiency of natural trees in the forests. Therefore, charcoal produced from mixed tree species is the most common sold product on the market. Some of the tree species include Mbanga *(Pericopsis angolensis),* Nkuyu *(Ficus Natalensis),* Tsanya *(Colophospermum mopane)*, Mkhuthe, Kanyanyata, Mango *(Mangifera indica)*, Branchystegia.

Normally charcoal suppliers take 2 to 4 days to finish selling the product during the rainy season due to its high demand and scarcity on the market. The study found that heavyweight charcoal packed in median sack bags (flat) is the most preferred and quick sold category on the market because it is economical.

Respondents know and are aware that selling charcoal is illegal hence facing a lot of challenges during their business operation. Law enforcement agencies seize charcoal bags in the production sites, roadblocks and marketplaces. When vendors get caught/arrested and charged in court they pay a fine to Government and fail to do so they are compelled to serve in jail for some years. As a means of survival, vendors pay money (bribe) in roadblocks to pass through with the charcoal. Vendors lose startup capital for the business in a situation where forest rangers have confiscated the charcoal.

Since the price of charcoal is unregulated on the market, customers usually bargain for price reduction thereby making small returns. Besides every seller could set any amount either high or low henceforth making stock clear faster or overstay on the market. A tendency of selling charcoal at a cheaper price to get immediate money to pay bills to make the charcoal business unprofitable.